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NOTICE

USSR REPORT

SPACE BIOLOGY AND AEROSPACE MEDICINE

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CONTENTS

SURVEYS

PREFLIGHT DIET FOR FLIGHT PERSONNEL

[Article by I. G. Popov]

[English abstract from source] The evolution of the concepts of preflight diets of flight personnel in the USSR and in other countries is discussed from the historical point of view. On the basis of the literature and his own data the author describes the main stages in the evolution associated with changes in the physiological-hygienic requirements for the diets and increases in the flight altitude, range and speed. The data on the arrangement of preflight meals, their composition and nutrient parameters are given. Physiological-hygienic requirements for preflight diets of flight personnel are determined in the light of present-day concepts and their further developments are outlined.

[Text] Preflight diet is an important element in the set of measures referable to psychophysiological preparation of flight personnel for missions varying in nature and purpose. It is directed at maintaining metabolism and energy at an optimum level, providing pilots with adequate amounts of nutrients, particularly those that are intensively utilized by the body during flights. Objective conditions are created by wise organization of preflight diet for maintenance and preservation of high work capacity during flights in the presence of adverse factors of flight work and neuropsychological tension to the extent of stress states. Preflight diet, which aids in preserving health and high work capacity of flight personnel, also plays an important part in assuring flight safety [1-4].

Preflight diet is not infrequently viewed as an element or variant of "ground-based diet of flight personnel [middle of sentence missing] ...according to flight standard of sufficiency." Indeed, it is organized similarly on the ground and on the basis of using the routine daily flight allowance (ration). At the same time, considering the strategy of conditioning pilots for complicated flight work, all ground-based nutrition of flight personnel can be viewed as preflight diet, particularly under conditions where the order to prepare for a flight or the need for an immediate flight can appear at any time [1-5]. However, in routine practice, preflight diet refers to all food intake about 24 h before the start of a flight and, not infrequently, intake of food issued just prior to take-off.

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Intake of preflight food (breakfast, lunch or dinner) is more often organized at a permanent specialized mess-hall [dining room] for flight personnel, but it can also take place directly at the main, alternate or intermediate airport, particularly during the breaks between flights. The main meals are usually organized in the flight mess-hall: breakfast, dinner [lunch], supper, and at an airport--lighter meals: lunch or supper [1, 3].

We can distinguish six main aspects of development of preflight diet, which have always concerned researchers and have not lost their significance to this time; they apply to routine practice in organizing nutrition for flight personnel: mandatory preflight intake of food, nutritional value of preflight food intake, hygienic requirements of types of foods and how they are cooked; physiological-hygienic requirements of preflight mealtime schedule, sanitary-hygienic requirements for organization and safety of preflight meals, medical supervision of preflight nutrition of flight personnel under different conditions of flight work.

The urgent need for mandatory intake of food before take-off was advanced by the acutal practice of flight work at the dawn of aviation. It became particularly important to organize mandatory preflight food intake at airports, with sufficient nutritional value, during the periods of difficulties and restrictions in providing food for pilots and their families. This happened, for example, during the period of recovery of the national economy after the end of the Civil War and during the Great Patriotic War. In 1930, for example, flight personnel received the main "Red Army ration" (3634 kcalories) as their daily food allowance, which contained 123.7 g protein, 63.3 g fat, 618.2 g carbohydrates, as well as a supplemenal monthly diet ration (1620 kcal) in order to increase calories and quality of diet (23 g protein 58 g fat and 240 g carbohydrates per day) [5, 6]. It would appear that these rations, which had a rather high energy value and nutritional value with regard to the main nutrients, constituting a total of about 5254 kcal/day, should have provided for proper daily intake of food for flight personnel on the ground with all forms of professional activities. However, in practice, this all turned out to be more complicated. As a rule, these rations were issued "in kind," in the form of assortments of foods and they were used essentially in the home, for the entire family. Under such conditions, it was virtually impossible to set any hygienic standards for the diet of flight personnel with respect to both its quantitative and qualitative parameters, as well as mealtime schedule, including preparations for flights. It was also extremely difficult to implement medical supervision of individual nutrition of flight personnel. Even then, it was noted that taking off in a hungry state or after minimal preflight food intake had an adverse effect on pilot endurance of flight factors, particularly at high altitudes; it affected well-being and work capacity of pilots in flight, and this worsened the quality of performance of flight assignments [6-8]. Considering the actual social and hygienic conditions with regard to nutrition of flight personnel at that time, as well as the need to perform safely the increasingly difficult flight assignments under the most diverse climate conditions, "supplemental hot breakfasts" were introduced already in 1931. They were provided for flight personnel in addition to the above-mentioned rations, which were issued to pilots and used in their homes. The supplmenetal food allowance was usually consumed by pilots right at the airport, before morning take-offs as a rule [6, 8]. As stated by F. G. Krotkov, "Hot breakfasts at

airports were adopted in order to guarantee mandatory intake of a certain amount and quality of food before flights. At the same time, such a system of nutrition made it possible to have such an important factor, from the standpoint of hygiene of nutrition, as intake of food in the mornings under control of a physician" [6]. The supplemental hot breakfast, with caloric value of 1315 kcal, contained an average of 55 g protein, 35 g fat and 226 g carbohydrates [5, 6, 8]. According to the data of other authors, the hot breakfasts adopted in 1931 had a caloric value of 1416 kcal, containing 60 g protein, 33 g fat and 175 g carbohydrates [9]. In the opinion of aviation hygienists of that time, this amount of calories had to reliably provide pilots with energy and the main nutrients during short-term flights. In essence, this was the first attempt to organize purposeful preventive preflight nutrition for flight personnel, although the very term, "preflight nutrition," did not yet exist.

Addition in 1931 of the special preflight nutrition in the form of hot breakfasts issued to flight personnel at airport mess-halls justified itself entirely, since it was instrumental in increasing work capacity of pilots during flights and lowering the accident rate. For this reason, in order to further improve the diet of flight personnel, a hot dinner [lunch] was added in 1936, which the pilots received at the airport. This dinner provided the hygienically regulated preflight diet for pilots on urgent flights in the second half of the work day or flights that were scheduled in the afternoon. Hot dinners were introduced instead of the former supplemental dietetic ration, the items of which were handed to the pilots. The energy value of the hot dinners constituted an average of 1840 kcal [12-14], i.e., it was greater than that of preflight breakfasts. Such improvement of preflight nutrition justified itself completely for flights in both the first and second half of the day.

Further development of preflight nutrition was related to introduction of a new, standard daily food allowance for flight personnel in 1941. As evidenced by G. A. Arutyunov, who headed this work, the need for a standard flight food allowance and organization thereof on the basis of centralized meal provisions for flight personnel in mess-halls at airports was attributable to the fact that flights started to be made both in the daytime and at night, whereas pilots received only hot breakfast and dinner. The new organization of nutrition made it possible to reliably provide flight personnel with preflight meals at any time of day, as well as to organize professional-preventive diets referable to the specifics of flight work.

New standards for pilot diet were adopted with the start of the Great Patriotic War (in September 1941), which provided for several types of ground-based rations. Allowances with higher amounts of nutrients were intended for the crews of aircraft of the army in action. During the war, as well as after it ended, up to 1951, the preflight diet of flight personnel was based on these allowances: nutritional value 4692 kcal, with 167.5 g protein, 124.4 g fat and 694.8 g carbohydrates.

In the years that followed, preflight meals were also organized on the basis of the daily ground-based allowances intended for flight crews of both engine-propeller and jet, turboject, turboprop aircraft, the allowances for whom were somewhat greater in nutritional value [1-4, 10].

Thus, a preflight diet gained a firm place in the system of nutrition for flight personnel as an important professional and preventive measure to improve pilot work capacity in flights that started at any time of day. This thesis was reflected in all current official manuals of flight personnel diet where it is written, in rather categoric form: "Preflight food intake is mandatory, since it increases work capacity and endurance of pilots," "It is inadmissible to take off for a flight on a fasting stomach," etc.

The urgent need to organize wise preflight nutrition put several difficult tasks to aviation medicine. Among them, the ones requiring priority attention were referable to nutritional value and amount of food in the preflight allowance, as well as choice of optimum mealtime schedule before flights. The complex [combined] solution of these problems throughout the history of development of preflight nutrition was closely linked to the specific physiological and hygienic distinctions of flight, state of aviation equipment, level of sophistication of onboard life-support systems, as well as problems and methods of psychophysiological preflight pilot training. It is not surprising that the very nature of preflight nutrition, its professional and preventive orientation underwent some changes, both under the influence of progress in aviation technology and as a result of the advances in aviation medicine.

At the early stage of development of aviation (in the 1930's), when the speed, duration and altitude of flights were relatively low, the main purpose of preflight meals was to prevent a decline of pilot work capacity under the specific flight conditions, in order to perform more efficiently the flight assignments and control accidents. For the first 10 years of development of Soviet aviation, this problem was solved on the basis of experience in backing up flights, with consideration of the scientific advances in the area of human physiology and hygiene of nutrition, as well as several theses of military hygiene of that period. In summarizing the experience in medical support of flights, G. M. Popov wrote, in one of the first manuals of aviation hygiene: "One cannot fly on a fasting stomach, so that the feeling of hunger would not disrupt equilibrium in the body, which is so necessary in flight" [7]. In hygienic recommendations of the 1930's, it was stressed that "a nourishing breakfast should be taken before a flight, but not one that is heavy for the stomach, with a small amount (1-1.5 glasses) of fluid. At the same time, it should be borne in mind that overloading the stomach could also have an adverse effect on function of the lungs and cardiovascular system, and consequently on endurance" [7]. These recommendations, which were based primarily on observations of flight personnel, have not lost their significance to this day. We were unable to find more precise recommendations concerning preflight nutrition in the literature of that period. However, no doubt questions of preflight nutrition troubled aviation physicians and flight operation officers, and work in this direction was being done by Soviet researchers. The first practical result of the work done to improve preflight nutrition and hygienic requirements referable to it was the introduction in 1931 of hot breakfasts at airports with standardized nutritional value. Up to 1939, this form of nutrition of flight personnel is mentioned in the literature as "nutrition at the airport," although in fact this was already a real hygienic rule for preflight nutrition. "The hot breakfasts at airports," which were introduced in 1931, had to have a nutritional value of about 1315 kcal and contain an average (assimilable) of 55 g protein, 35 g fat and 226 g carbohydrates [5, 6, 8].

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We were unable to find a comprehensive physiological and hygienic validation of nutritional value of hot breakfasts in the literature. F. G. Krotkov wrote in this regard that "from the standpoint of hygiene of nutrition, the caloric value and assortment of foodstuffs issued for the preparation of breakfast raises no serious objections" [6].

The above-mentioned breakfast corresponded to about 36% of the daily caloric value of the main daily food allowance for pilots based on the "Red Army rations," which were issued to them for taking meals mainly at home. Hygienic requirements concerning optimum distribution of food over different meals were based at that time mainly on the recommendations of Rubner and Noorden. According to Rubner, the optimum distribution was considered to be intake of 20% of the daily allowance, according to caloric value and amount of food, for breakfast, 46% for dinner and 34% for supper. According to Noorden, 35% of the daily amount of food was to be taken at breakfast, 25% at dinner and 40% at supper. The diet according to the "Red Army rations" of that period provided for the following distribution of the daily allowance: 30% for breakfast, 50% for dinner and 20% for supper. F. G. Krotkov concluded that this was close to the recommendations of Rubner [11]. "Hot breakfasts" for pilots, which had a caloric value of 36% of the daily allowance (but issued as a supplement) conformed better to Noorden's larger breakfast.

For the "hot breakfasts at airports," adopted in 1931, the hygienic standard covered not only nutritional value, but assortment of foods issued. While there was no regulation of the assortment of foods up to the 1930's, with the introduction of hot breakfasts in 1931, there was distinct definition of the foodstuffs they contained. The following items had to be used for the preparation of hot breakfasts at the airport: wheat bread 200 g, flour for thickening 10 g, various grains 20 g, macaroni 15 g, meat 250 g, butter 20 g, fresh vegetables 200 g, sugar 20 g, fresh milk 200 g, tea 0.8 g, salt 10 g, as well as pepper and bayleaf [6]. This assortment of foods made it possible not only to prepare tasty and diversified hot meals, but provide for preflight nutrition with a considerable amount of assimilable proteins and carbohydrates. At the same time, researchers of that period believed that it was desirable to increase the fat content of breakfasts at the expense of butter, increase sugar allowance, reduce the amount of meat and add fish and dairy products to diversify the diet [6].

The further increase (in 1930-1940) in duration of flights, altitude, speed, as well as maneuverability of aircraft, was associated with increased requirements with regard to health and work capacity of flight personnel during flights. This made it necessary to pay even more attention to questions of psychophysiological and other special training of crews, particularly preflight nutrition.

Considering the changing working conditions for flight personnel and requirements of physiology and hygiene of nutrition of that period, new diet standards were worked out for flight personnel, which were adopted in 1936. In accordance with these standards, it was mandatory to provide not only hot breakfasts, but hot dinners at airports. The preflight hot breakfast of 1936 had a nutritional value of 1594 kcal, and it contained 57.6 g protein, 55.8 g fat, 213.3 g carbohydrates; the dinner had a value of 1840 kcal, with 60.0 g protein, 61.1 g fat and 206.2 g carbohydrates [12-14]. In the opinion of S. S. Kholin, who worked out these standards, the amount of protein, fat and carbohydrates provided by the standards for flight personnel nutrition, even without counting food intake

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at home, compensated for the main energy expenditures of pilots [12]. Indeed, the overall nutritional value of the breakfast and dinner constituted 3434 kcal (118 g protein, 117 g fat, 502 g carbohydrates) which, taking into consideration the supper at home estimated at about 30% of the daily allowance, should have conformed to the physiological nutritional standards of those times for heavy physical labor [12]. The increase in assortment of food items, from 13 to 28, for breakfasts and addition of 43 new items for dinners were also very important. This made it possible to prepare diverse dishes out of meat, fish, fowl, eggs, as well as dairy, starch, grain, vegetables and fruit. Special attention was devoted to enrichment of food with easily assimilated protein in the form of dairy products. Increasing attention was given to vitamins. Vitamin intake was provided in the form of vegetables, fruit and butter [12-14].

In the late 1930's and early 1940's, much importance was attributed to a wise meal schedule during flight training (particularly for high-altitude and long-term flights). Attention was given to the need to adhere to specific intervals between preflight food intake and the start of the flight, and consideration was given to the volume of food and speed of assimilation thereof.

On the basis of data concerning the state of the gastrointestinal tract at high altitude (distention, nausea, etc.), in 1937 S. S. Kholin recommended the following rules for preflight meals for pilots: "On ordinary days, before flights, flight personnel, like athletes in training, should adhere to regular intake of food at the airport, as well as at home at strictly set times. One can recommend tentatively the following mealtime schedule: breakfast betwe n 0700 and 1000 hours, dinner between 1200 and 1600 hours and supper between 1900 and 2100 hours." On flight days, the last preflight meal should not be too large and should be taken 1-2 h before take-off [12].

It was suggested that the menus of preflight breakfasts should include such dishes as omelet, fried eggs, cottage cheese pancakes, butter, white bread and (less often) meat. It was insistently recommended that aviation physicians require that, in preparing the menu sheets and meal schedule before flights, due consideration be given to altitude, duration and meteorological conditions [12, 13]. However, we were unable to find any concrete recommendations on this score. At that time, the question was only being raised of the need to determine assimilability of food and function of the gastrointestinal tract at high altitudes.

By 1936, on the basis of the accumulated experience and results of a number of studies, differentiated recommendations were worked out for routine short-term, as well as long-term and high-altitude flights [6]. We have already mentioned above the requirements of that period with regard to routine short-term flights.

During training for long-term flights, it was recommended that the composition of food dishes and nutritional standards be defined in accordance with the objectives and conditions of flight, as related to the mode and schedule of a concrete flight. Determination had to be made early enough of the nutritional status of crew members and, if necessary, supplemental food intake was to be ordered [6]. Before take-off and then during flight, it was proposed that the allowance include adequate amounts of vitamin-containing food. In 1936, F. G. Krotkov wrote that pilots should be offered a large hot breakfast before flying, corresponding to one-third the daily allowance and containing

40-50 g protein, 35-40 g fat and 200 g carbohydrates. The dishes had to be prepared of such well-assimilated and complete foods as eggs, meat, fish, dairy products, fresh vegetables and white bread. The energy value of the preflight breakfast had to be at least 1300-1400 kcal [6].

In spite of improvement of preflight diet and adoption of supplemental onboard nutrition, pilots still developed considerable fatigue and their work capacity diminished during long-term flights. For this reason, the idea was advanced of improving work capacity and controlling fatigue by means of alimentary factors that had specific effects. As a positive and promising direction, experiments are described where pilots consumed South African cola nuts 1-2 h before a flight. According to the data of S. I. Subbotin, during long-term flights 3-4 g cola nuts had a tonic effect on the central and autonomic nervous systems, improved mental and physical work capacity and general well-being. The effect of this dosage lasted 12-36 h. Cola nuts were used in the form of special tablets or in chocolate. At that time, there were no data on the effects of cola nuts during high-altitude and night flights. Yet F. G. Krotkov appealed for the use of some caution in using cola nuts [6, 15].

In 1930-1940, special attention was devoted to questions of improving nutrition during training for high-altitude flights. Aviation physicians were concerned primarily with steps to enhance resistance to low partial oxygen and barometric pressure. Much was expected, in particular, of development of special "high-altitude" food allowances. As far back as 1930, N. A. Trofimuk established in pressure-chamber experiments that the maximum altitude of ascents on a fasting stomach was 3500 m, whereas after intake of a sufficient amount of food calories it was 5500 m. He recommended intake of a moderate amount of food and drink 1-1.5 h before a flight to assure a beneficial outcome of high-altitude flights. At the same time, the undesirability of taking foods that produce much gas in the intestine was noted [8].

The experience of supporting the first high-altitude flights revealed that one should exclude from preflight meals foods that are rich in cellulose and yield a large amount of undigested mass causing increased gas production in the intestine in order to prevent high-altitude tympanites. Such foods included ryebread, cabbage, leguminous, dairy products and carbonated water. The "altitude pain" in the abdomen, nausea and even vomiting, which were not uncommon in those days, were properly attributed to "distention" of the intestine by gas when ascending to high altitudes. These phenomena were named altitude meteorism [tympanites]. Introduction in 1931 of the hot breakfasts at airports was intended to support expressly high-altitude flights [6]. By 1936, physiological-hygienic requirements had already been formulated for organizing the nutrition of "high-altitude fliers," which were defined as follows by F. G. Krotkov in one of his works: "When preparing for flights, it is necessary to adhere to a wise mealtime schedule: 1) mandatory intake of food before flying and not later than 1-1.5 h before take-off; 2) do not consume foods and dishes rich in cellulose at breakfast; 3) avoid large amounts of milk and carbonated water; 4) take in more fat and carbohydrates; 5) by no means to consume alcoholic beverages on the day before and of the flight; 6) check for regular evacuation of the intestine, resorting to enemas and laxatives if necessary; 7) the high-altitude breakfast should contain about 1500 kcal, with 50-60 g protein, 50 g fat and 200 g carbohydrates; 8) it is recommended that the dishes include the

following: white bread, eggs, cheese, cottage cheese, sour cream, caviar, meat, fresh fish, sweetened tea or coffee, cookies, sweet rolls" [6]. Many of these recommendations have not lost their relevance to this day.

The research done in 1937-1941 by Soviet scientists played a large part in working out problems of physiology and hygiene of preflight nutrition for flight personnel when preparing for high-altitude flights, when conditions may develop for occurrence of hypoxia: P. I. Yegorov [16], V. V. Strel'tsov [17, 18], G. Ye. Vladimirov [19, 20], S. S. Kholin [12, 13], O. P. Molchanova [21, 22], G. A. Arutyunov [23-25], I. P. Razenkov [26] and others. Their recommendations with regard to preflight nutrition for high-altitude pilots were based primarily on data obtained with the use of pressure chambers and high-altitude expeditions, and to a lesser extent on material that was gathered directly during high-altitude flights. The results of experiments in pressure chambers and high-altitude hikes indicated that certain changes develop in hypoxic states in animals and man with reference to metabolism and functional state of the gastrointestinal tract [17-26]. The above-mentioned recommendations gained wide use in aviation, and their desirability was confirmed by the practice of high-altitude flights. At the same time, tasks were formulated for further, more in-depth investigation of assimilation of food and functional activity of the gastrointestinal tract, as well as its glands, during high-altitude flights [17, 18, 24, 25].

The works referable to that period again mentioned such phenomena as distention of the intestine and nausea during high-altitude flights, which required adherence to a regular mealtime schedule, development of special menus and regimen for food intake. It was necessary to forbid intake of foods that produce gas in the intestine, particularly cellulose of plant origin. For this reason, intake of fruit and vegetables was limited on flight days. In view of the low temperature at high altitudes, high-calorie fats with low melting point started to be included in the diet. Only readily assimilated protein was consumed. Evacuation of the intestine was necessary before take-off [13, 24].

Hygienists concerned with questions of flight personnel diet, no doubt, took into consideration the latest data referable to high-altitude physiology and the practical experience of flight personnel [23-25, 28], and primarily the works of I. P. Razenkov, G. Ye. Vladimirov, V. V. Strel'tsov and other authors [16-20, 26, 27]. Due consideration was given not only to data on the effect of hypoxia on the state of the gastrointestinal tract and metabolism, but about adaptive changes in the body with repeated ascents to high altitudes, as well as progress in development of onboard and personal life-support equipment. Since the previously developed recommendations for optimum nutrition of pilots were still in effect, the requirements of preflight nutrition were in the nature of a compromise, to some extent, rather than only serving the purpose of preventing hypoxia. This is demonstrable the most distinctly in recommendations made in 1939 by G. A. Arutyunov and S. S. Kholin [23, 24], which were later confirmed by V. V. Strel'tsov [18] and V. A. Spasskiy [28]. The main requirements and sets, on the basis of which one can plan the diet of flight personnel should, according to these authors, be as follows: 1) the diet should provide for complete coverage of energy expenditure and be instrumental in enhancing resistance to high altitude; 2) organic foods

(protein, fat and carbohydrates), vitamins and minerals should be contained in the daily food allowance of flight rations in sufficient amounts to take care of all body expenditures; 3) the diet of flight personnel should conform entirely to their work schedule [mode]; 4) the foods and dishes made with them should be readily assimilated and produce the minimal amount of waste (residue) in the gastrointestinal tract; 5) the food for flight personnel must be of top grade, high quality, in both raw and cooked form; 6) the food should have a pleasing flavor, provide adequate satiation without causing a heavy feeling, it must be easily digested and assimilated; 7) the food should not consist of products that cause production of large amounts of gas in the intestine [24]. At the same time, G. A. Arutyunov and S. S. Kholin stressed that "at the present time, we do not yet have data with sufficient scientific validation concerning questions of physiology and hygiene of nutrition for individuals engaged in flight work, but work has already begun on many of these questions" [24]. Slow development of research on physiological and hygienic validation of diets for flight personnel was noted and even criticized by A. A. Sergeyev [29]. In addition to general hygienic requirements, G. A. Arutyunov was the first to offer comprehensive recommendations on making up preflight menus, choice of foods and prepared dishes, their nutritional value in routine and high-altitude flights [24].

Questions of preflight diet as related to high-altitude flights were the subject of a rather large number of studies in the United States, England and other foreign countries [30-32]. Attention was devoted specially to work on scientific and applied questions of the effect of altered diet on resistance to anoxia. Considerable material was accumulated, as a result of both experiments with animals and studies of humans. The results of studies of the effects of composition of preflight meals on resistance to altitudes of 4570-5200 m are very interesting. According to their findings, abstention from food for 4-5 h before a flight is the least favorable. Best were breakfasts with high carbohydrate content. Food with 20, 30 and 40% protein content diminished resistance to high altitudes [33]. Fat occupied an intermediate place [30, 33]. It was demonstrated [34] that preflight breakfasts consisting of carbohydrates amounting to 69% of total caloric value, 21% fat and 10% protein, as compared to meals with equal amounts of these nutrients, were best for ascents to 5200 m without oxygen. The authors observed that "in the case of combat flights, the most insignificant psychological and psychomotor coordination disturbances could result in the wrong decision being made by the pilot, or even loss of the aircraft. The demonstrated advantages of carbohydrates could be quite important to flight safety and piloting qualities" [34]. Other authors arrived at similar conclusions [30, 35, 36]. Summing up the research that had been done up to 1951, Mitchell and Edman concluded that preflight and inflight carbohydrate diet, as compared to protein diet, improves mental and physical work capacity, as well as neuromuscular coordination of pilots [31, 32]. A considerable number of studies conducted abroad dealt with the importance of vitamins A, C and B to high-altitude resistance. Although it had been found that there was an increased need for ascorbic acid, thiamin and nicotinic acid in the presence of anoxic anoxia, the results were contradictory. This warranted the conclusion that a vitamin supplement to a proper diet apparently did not enhance resistance to anoxia [31, 32]. To some extent, this conclusion raises some question of the efficacy of supplemental vitamin content of preflight food, but does not minimize the importance of proper preflight diet with regard to physiologically standard levels of vitamins.

The results of studies dealing with high-altitude physiology and hygiene of nutrition for pilots, which were pursued in our country and abroad in the 1940's-1950's, definitely had a serious influence on development of preflight diets. Many recommendations have retained their importance to this day and, with some corrections, continue to be used in practice.

With increase in speed capability of aircraft, more and more attention was given in aviation medicine to the effects on pilots of accelerations and to development of preventive measures to enhance pilot resistance to them. Very logically, the attention of scientists was drawn to such questions as the state of the gastrointestinal tract, digestive processes, assimilation of food and metabolism with exposure to accelerations. There are relatively few data on these questions in the literature of the 1940's-1950's and subsequent years, as compared to data dealing with the effects of hypoxia as a factor of high-altitude flights. Thus, F. G. Krotkov, in summarizing the data of Diringshofen, only makes brief mention of the fact that accelerations and vibration of the aircraft elicit secretion of gastric juice via the autonomic nervous system. For this reason, it is not recommended to fly on a fasting stomach without taking repeated meals (every 4 h) in flight [14, 37]. D. Ye. Rozenblyum [39] reported in 1941 that, in studies on a centrifuge and in flight, it was noted that the subjects tolerated higher accelerations after meals than before meals. After taking food, endurance on the centrifuge increased by 1.5-2 G with exposure to accelerations for 3-4 s. In his opinion, the beneficial effect was related to the fact that "at the height of digestion" (according to I. P. Razenkov) physiologically active substances pass into blood, which improve vascular tonus and have a vasoconstrictive effect [39]. On this basis, in the instructions for flights referable to that period, it was considered mandatory to eat 1 h before take-off. According to D. Ye. Rozenblyum, the Germans and English also insisted on a breakfast before take-off. He stressed that flying on a fasting stomach diminishes resistance to accelerations [39]. However, in the same manual, in the section dealing with pilot diets, nothing is said about the need to consider the acceleration factor in the preflight period, and all attention is concentrated on the nutritional distinctions during training for and performance of high-altitude flights. The authors of other works referable to the same period continued to adhere to the same orientation [11, 17, 24].

In the 1950's, because of the intensive development of jet aircraft, there was drastic increase in interest for investigation of the effect of accelerations on the body and development of appropriate protective measures. In their work dealing with questions of pilot diet at high-altitudes, Mitchell and Edman [30, 31], in 1951, dwelled specially on the importance of the acceleration factor to meal scheduling. They reported that Clark and Jorgenson had demonstrated an increase in man's resistance to accelerations after intake of food and liquids. The only factor that could explain the mechanism of increase in resistance to accelerations is, in their opinion, an increase in pressure in the abdominal cavity. Intake of liquids and food increases the force of cardiac contractions without involvement of vasomotors and without displacement of blood from the periphery to internal organs [30]. In view of the established fact that elevation of blood sugar is associated with enhancement of resistance to accelerations, special studies were conducted to determine the effects of hypoglycemia and hyperglycemia on resistance to accelerations. However,

the difference in endurance was found to be insignificant, about 0.2 G [30].
Armstrong also mentioned the beneficial effect of nutrition on exposure to
accelerations, and he confirmed data to the effect that, with a full stomach,
tolerance of "accelerations" increases by 1-2 G, but he did not offer an explana-
tion for this fact [40]. In the literature of subsequent years, there are
also very few data about the effect of accelerations on the gastrointestinal
tract and metabolism, and virtually no practical suggestions are offered for
preflight nutrition. It is reported, for example, that marked inhibition of
secretion of saliva and, to a lesser extent, gastric and intestinal secretions
was demonstrated after termination of exposure to radial accelerations in
experiments on animals. It was concluded that maximum inhibition of secretion
is observed in glands that are controlled mainly by the central nervous system.
Delayed emptying of the stomach was reported. It was confirmed that man is
more resistant to accelerations after intake of food than on a fasting stomach
[1, 41, 42]. The results of some other studies with animals also confirmed
the effect of accelerations on the gastrointestinal tract [43-62]. However,
several authors continued to believe that flights in modern aircraft have no
pronounced effect on assimilation of foods, and they proposed that one proceed
from the usual levels of assimilation of foods adopted as the average for the
healthy adult population to estimate the nutritional value of preflight food
allowances. Nevertheless, the acceleration factor was mentioned more and
more often, along with altitude factors of flights in the recommendations for
preflight nutrition. Preflight intake of food must be mandatory, since it en-
hances considerably endurance of high-altitude flights and accelerations.
The preflight meal should consist of foods that are digested and assimilated
rapidly and readily. It was confirmed that overloading the stomach is not
desirable, since it makes respiration more difficult, reduces vital lung
capacity, could elicit pain and vomiting in flight, which is particularly
dangerous when using oxygen gear. There should be an interval of 1.5-2 h
between intake of food and flying, so that most of the consumed food has had
time to leave the stomach. It was believed that carbohydrates should consti-
tute 60-65% of the total calories, proteins 10-15% and fat 25-25% [sic] in
the preflight meal. The fat restriction was validated by the danger of
ketosis in the presence of hypoxia. The increase in carbohydrate content
was due to the desire to normalize fat metabolism. A surplus of protein was
considered undesirable. Intake of foods rich in lecithin (egg yolk, brains,
liver, cheese, etc.) was recommended to prevent disturbances of acid-base
equilibrium. At that period, special attention began to be devoted to regular
vitamin supplements in the diet of pilots, since studies had established that
there was a higher vitamin requirement with flight work. For this purpose
it was recommended that multiple vitamins be issued daily, which contained
vitamins A (2 mg), B_1 and B_2 (3 mg each), C (100 mg) and PP (10 mg). Special
importance was attributed to vitamin B_1, because of the high carbohydrate
content in the preflight meal. On the other hand, G. A. Arutyunov, V. M.
Vasyutochkin, Yu. F. Udalov and a few other authors [11, 25, 42, 63-86, 88-93]
recommended large doses of vitamin C and B complex.

Although the oxygen-breathing gear had been substantially refined, as far
back as 1959 it was recommended that dishes be included in the preflight meal
that had no coarse mechanical admixtures, and were rich in chemical stimulators
of digestion (strong beef broth, broth from cooked vegetables, chopped herring,
ground meat, various souces and gravies, cheese, lemons, coffee, tea). It was

also recommended that food be spiced with such items and flavor enhancers as onions, garlic, pepper, vinegar, mustard, spices, but in reasonable amounts, so as not to elicit severe irritation of the gastrointestinal tract. These recommendations were based on the data of I. P. Razenkov [26] and other authors concerning the inhibitory effect of hypoxia on secretory and peristaltic function of the stomach. Serious attention was devoted to prevention of high-altitude meteorism, but now only in the case of cabin depressurization.

At the present time, much attention is given to organization of preflight meals in the system of psychophysiological training of flight personnel. In a number of manuals and articles, preflight nutrition refers to all intake of food occurring about 24 h before a flight and, particularly, food intake before take-off. In practice, medical supervision thereof involves essentially the meals taken in the specialized mess-hall, which are offered just prior to flights and in the breaks between them at airports. In the case of particularly complex flights (test flights, high-altitude, etc.), there are higher requirements for preflight meals. It is recommended that flight personnel be put on the preflight diet 1 day before a flight and on the day of preliminary preparations in order to prevent metabolic disturbances and altitude meteorism [1, 3, 42].

At the present time, one should impose a number of physiological and hygienic requirements of preflight nutrition. First of all, it should be directed toward providing for high physical and mental work capacity of pilots during flights, as well as enhancement of tolerance of specific physicochemical flight factors, primarily accelerations. In addition, it should create a certain reserve of nutrients in the body in the event of stress situations and need to mobilize all of the pilot's physical and neuropsychological capacities. The preflight diet should have provisions for the possibility of emergency situations (depressurization of the cabin, necessity to eject or abandon the aircraft with a parachute, malfunction of oxygen-breathing gear, etc.). Finally, preflight nutrition must be impeccable with regard to sanitary and hygienic qualities, to rule out the possibility of dyspeptic signs, food poisoning and toxic infections, particularly during flights, as well as infectious diseases that are transmitted through food. The preflight diet, which has a beneficial effect on preserving health and work capacity of pilots and takes into consideration the above requirements, is an important element in assuring the effectiveness and safety of flights.

At the present time, as well as throughout the history of development of flight personnel diets, in order to meet these physiological and hygienic requirements, it is stressed that there is an urgent need to take food before flying, since this improves work capacity and endurance of pilots [1, 3-5, 41, 42, 87, 93-95].

Proper organization of preflight meals plays a large part. In order to provide optimum preflight meals for flight personnel in airport mess-halls, the weekly menus should include dishes and foods that conform in their properties to the requirements for preflight meals. With such organization of pilot nutrition when preparing for flights, the pilots can have a preflight meal at any time of day. During the period of preparing [training] for a flight, it is recommended that foods made at home and elsewhere be excluded. This is important with regard to sanitation, hygiene and epidemiology, to assure flight safety.

The food used for meals at the airport should conform to the physiological and hygienic requirements for preflight meals [1, 42]. As to scheduling of preflight meals, the main requirement is still in effect: flights should start no sooner than 1.5-2 h after intake of food. In order to preserve high work capacity of pilots in the course of the work day (flight shift), it is recommended that, after spending 4 h at an airport, they be given a second preflight breakfast or second supper, dinner. These recommendations are closely related to the general physiological and hygienic requirements concerning the mealtime schedule for pilots, according to which flight personnel should take hot food 4 times a day at intervals of no more than 4-5 h during the waking period (including meals in flight) on flight days [1, 3, 41, 42].

At the same time, it is noted that the preflight meal should not be large. A heavy feeling and other discomfort in the abdominal region, tachycardia, breathing difficulty, particularly in seated position, reduction of vital capacity since the diaphragm is shifted up and makes respiratory excursions difficult appear with intake of too much food just before a flight. There may also be development of pain of varying intensity in the region of the abdomen, nausea and even vomiting, particularly during maneuvers, which could serve as grounds to abort a flight or an accident [1, 3, 41, 42].

Food taken just prior to a flight must consist of items that are readily digested and assimilated, so as not to extend the period of intensive digestion in the stomach and assure faster migration of nutrients into blood. It is also necessary for the volume and weight of preflight food not to exceed the existing requirements.

The first main preflight breakfast in the mess-hall should constitute no more than 20-25% of the total calories for the day's food allowance, the second breakfast served at the airport in breaks between flights should not exceed 10-15% thereof. The total recommended caloric value of the main (first) preflight breakfast is 800-1200 kcal. Preference should be given to foods that are rich in readily assimilated carbohydrates (white bread, sugar, fruit juices, chocolate, candy), which prevent hypoglycemia and contain essential amino acids and vitamins [1, 41]. The caloric value of food served at the airport as the second breakfast (or second supper in the case of night flights) should not exceed 700 kcal. The second breakfast (supper) should include mainly readily assimilated carbohydrates and protein (white bread, cheese, eggs, sausage, sugar, chocolate), as well as hot coffee and tea [1].

The following menu sheet can be submitted as a first preflight breakfast: meat patties with garnish (100 g meat, 54 g macaroni), rice pudding with sweet sauce (22 g rice), bread (140 g wheat, 50 g rye), sugar (25 g), butter (15 g), tea. The second breakfast at the airport consists of the following items: bread (wheat) 50 g, cheese 15 g, chocolate 15 g, 1-2 eggs, sugar 20 g, coffee with milk.

Although most modern aircraft have pressurized cabins, in which pressure is kept at 405 mm Hg or higher, there is always the danger of depressurization, which could lead to altitude meteorism in the intestine [1, 3, 41, 42]. In order to prevent altitude meteorism, foods that are rich in cellulose, that is digested poorly and slowly, which causes increased gas production in the

intestine, is not recommended for preflight menus in order to prevent altitude meteorism during high-altitude flights. Moreover, cellulose, which causes mechanical irritation of the intestine, causes faster passage of undigested mass into the lower parts of the intestine, which is associated with intensive production of gas. Alcoholic beverages have the same effect. Such foods include, first of all, turnips, horse radish, radishes, cucumbers, tomatoes, cantaloupe, as well as corn, peas, string beans and other leguminous vegetables, barley and oats, kvas [fermented, cider-like beverage]. Milk and apples are contraindicated for some people [1, 3, 41, 42]. Some foods of plant origin are allowed in preflight meals, but in limited amounts. For example, rye bread (day old) is allowed in amounts not exceeding 200 g, cabbage 100 g, potatoes 550 g and no more than 250 g of other vegetables. Many of these foods are deliberately omitted from flight diets (rations) or the quantities thereof are limited. As a rule, vegetables are used after being cooked, which breaks down and softens fiber. For supper on the day of preflight preparations, it is recommended to use items that depress fermentation processes in the intestine or cause passage of gas: onions, garlic, dill, sour milk products. The recommended amounts of main nutrients in the preflight breakfast are: 60-65% carbohydrates, 20-25% fat and 10-15% protein [1, 41, 42].

One should exclude from the preflight meal items that have a high fat content, particularly fatty pork and mutton, since secretory function of the stomach could diminish in the presence of neuropsychological tension, which makes digestion more difficult and causes it to last longer, and could also be the cause of dyspeptic disorders before and during a flight [1]. Passage of gases from the intestine is more difficult when one spends much time sitting down and with little exercise. For this reason, it is desirable to adhere in the preflight period to a schedule that includes adequate physical activity. Pilots must clean their intestine before a flight. Several foreign authors recommend special diets for flight personnel who fly at very high altitudes, in order to prevent gas production in the intestine and gastrointestinal disorders. Farmer believes that special dishes should be prepared for pilots, containing none or limited amounts of the following items: 1) fats and fat products; 2) highly concentrated carbohydrate products; 3) items with high amounts of gravies and spices, including catsup, chili sauce, garlic, mustard and meat gravies; 4) items that produce gas (raw apples, lemons, dry beans, peas, lentils, cauliflower, cucumbers, radishes, turnips, green onions, pepper, garlic, Brussel sprouts and carbonated beverages); 5) roughage such as items with high bran content, celery, berries. Although these rules of dietology are presently applied less often in view of reliability of cabins, they should be followed during conditioning in pressure chambers and in complicated missions [93].

Much attention is devoted to adherence to sanitary and hygienic rules in organizing preflight meals, particularly at airports. The food used must be delivered to the airport from the flight mess-hall in specially assigned vehicles and in appropriate containers. Main courses, coffee and tea should be served hot. Special rooms equipped with a stove to heat food, kettle, dishwasher, refrigerator and small drums with cold drinking water, should be provided for storage and preparation of food at the airport. It is forbidden to keep hot food for more than 1 h at the airport. Appetizers should be stored under the conditions and for the periods of time specified by State sanitary alimentary legislation [1, 42].

Analysis of development of problems of preflight diet for flight personnel enables us to conclude that many of the physiological and hygienic recommendations in effect at the present time appeared relatively long ago; however, in spite of the major changes in aviation technology and conditions of professional pilot work, they have not lost their importance to this day. At the same time, the rigidity and categoric nature of some requirements have diminished significantly due to the better quality of life-support systems in the cabins of flight vehicles, and also there have been changes in many flying conditions, as well as nature of professional work of pilots. However, the preventive role of preflight diets in general has not lost its importance. At the present time, along with questions of assuring flight safety and enhancing resistance to flight factors, development of problems of physiological and hygienic recommendations is acquiring increasing importance, since their main objective is to improve pilot work capacity during flights, by means of specifically influencing metabolism and psychophysiological capabilities with use of natural or artificially produced food items, as well as a wise regimen of preflight nutrition.

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STATIC ELECTRIC AND ELECTROMAGNETIC LOW-FREQUENCY FIELDS (BIOLOGICAL EFFECTS AND HYGIENIC ASSESSMENT)

[Article by B. I. Davydov and V. N. Karpov]

[English abstract from source] The literature data are used to analyze the hygienic situation when man is exposed to constant electrical and low frequency electromagnetic radiations. The spectral characteristics and intensities of electrical fields near and on the surface of the earth generated by natural sources of electromagnetic radiations (electrical quasi-static fields, atmospheric electricity, thunderstorm charges, electromagnetic radiation emitted by the sun and galaxies) are given. They can be employed to determine man's adaptive capabilities to the frequencies described during acute and chronic irradiation. The mechanisms of biological effects of the exposures are discussed. The methods for calculating the safety levels based on the USSR radiation safety standards and the "competing frequencies" procedure proposed can be applied to the design of electrotechnical devices and evaluation of integral hazard of constant electrical and electromagnetic fields of low frequencies.

[Text] The variations of electromagnetic fields [EMF] of our planet are determined mainly by electric and magnetic quasi-static fields of earth, atmospheric electricity, radiation from the sun and galaxies, general radiation background of numerous artificial sources. The specifics of flight work and work of technical personnel related to flights raise the question of assessing the levels of man's exposure to EMF [1, 2]. Atmospheric electricity is a natural source of electromagnetic radiation (EMR) that affects man. EMR from thunderbolts may present an occupational hazard to aircraft crews. The gradient of potential E of the atmospheric electric field near earth's surface depends on meteorological and local conditions, time of year and latitude of the locality. There are 5-10-fold differences in mean value of E for different points of the globe. The daily pattern of the electric field may be determined by local perturbances due to presence of nuclei of condensation, dust, smoke and degree of vertical exchange. The mean intensity near earth's surface is about 130 V/m [3]. When there is precipitation and, particularly, thunderstorms, as well as in a number of other instances, the field may change direction and reach about 10^4 V/m.

Figure 1 illustrates the daily change in electric field, which has been averaged for 2 years, in Voyeykovo on the surface of the earth and at an altitude of 100 m [4].
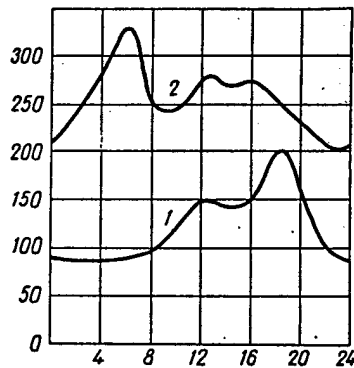
Figure 1.
Daily pattern of electric field potential in Voyeykovo averaged over a 2-year period
X-axis, time (Greenwich, hours); y-axis, intensity of electirc field (V/m); 1 and 2, intensity at earth's surface and altitude of 100 m, respectively [4]
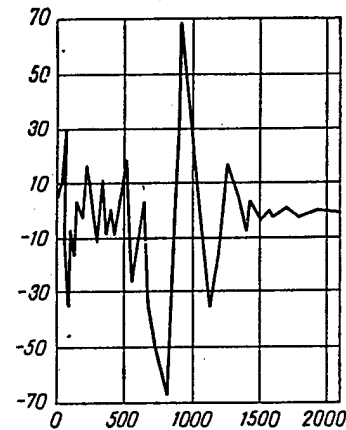
Figure 2.
Shape of wave of emitted electric field 1.6 km (1 mile) away from a bolt of thunder [8]
X-axis, time (μs); y-axis, field intensity (V/m)

Maximum EMF intensity generated by atmospheric disturbances constitutes about 10 kHz and diminishes with frequency. The intensity of the spectral band of 1 kHz also is a function of time and could exceed 0.1 V/m [5].

In good weather, the profiles of the electric field from earth's surface may be of four types: 1) positive intensity of field diminishes one-to-one with altitude; 2) positive field intensity diminishes one-to-one with altitude and, at a certain altitude, changes in sign; 3) electric field intensity changes with altitude nonmonotonically with a maximum at 300-700 m, and its sign changes often at 3000-4000 m; 4) "sluggish" profile of electric field, which changes little with change in altitude [6].

There must be a zone with $E \simeq 10^6$ V/m for a discharge to occur in a cloud. In addition to the danger of direct damage to the aircraft housing [7], there is a radiation hazard to flight crews from exposure to EMF emitted by the discharge of thunder. The mechanism of appearance of lightning is complicated. A discharge begins with slowly displaced, mildly ionized flux (streamer), which advances from a cloud to earth or from cloud to cloud in steps of 10-60 m at a velocity of 0.3-0.6 m/μs. This guiding flux is followed by a strongly ionized "leader," which moves at a speed of 60 m/μs, generating a current pulse of ~300 A lasting ~1 μs. Then the leading flux again advances in steps, and this process is repeated every 25-100 μs. These short pulses and the "leader," which occur at a frequency of 10-40 kHz, emit energy during the so-called pre-discharge period, the total duration of which is ~1000 μs. The shape of the wave emitted by the electric field at a distance of 1.6 km (1 mile) is illustrated

in Figure 2. Figure 3 illustrates the spectral characteristics of lightning
[8]. In addition to the above-mentioned continuous frequency spectrum, there
is demonstrable activity of the thunderbolt in the range of ultrashort waves
(USW) and superhigh frequencies (SHF) [9]. According to some data, the overall
pulse of lightning may exceed 3 kV/m at a distance of 10 km from the discharge
[10].
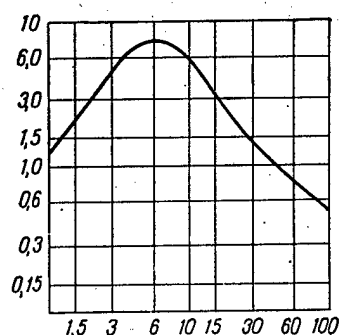
Figure 3.
Resultant frequency spectrum of pre-
liminary and main discharges scaled
to intensity at 1.6 km [8]
  X-axis, frequency (kHz); y-axis,
  intensity of electric component (V/m
  with bandwidth of 1 kHz)

Among the EMF arriving from space,
a distinction should be made of the
sun's radiation, which is approximately
constant [static] only when the surface
is free of sun spots and solar flares.
This is thermal radiation from free
electrons on the outer layers of the
sun. However, upon appearance of
solar spots and bursts, the intensity
of EMF could increase by hundreds and
thousands of times, and the isolated
surges in the meter-wave range arrive
in the form of series [trains] lasting
a total of about 1 min [11].
A continuous low-frequency component
of galactic EMF can be detected at any
point of the celestial sphere. It
should be noted that integral intensity
of cosmic EMF near earth is low, as
compared to fluctuations of its own fields, but it could become a deciding
factor in interplanetary flights.

The general radiation background undergoes considerable changes in time and in
space. For example, aircraft traverse zones of maximum radiation from radio
relay systems or television transmitters that have directional radiating
antennas just prior to landing, as they fly near inhabited regions. When
landing under poor meteorological conditions or at night, the aircraft is
accompanied by high-power narrow radar beams. The technical service [maintenance]
personnel are in the immediate vicinity of generators of powerful EMF or their
antennas. The intensity of EMF from artificial sources is directly related to
the power of generators, share of energy transmitted for emission, as well as
coefficient of directional [guided] action and distance to sources. The inten-
sity of antenna fields can vary from hundreds of microvolts to hundreds of
volts per meter. The inherent distinction of artificial source is their
high coherence--frequency and phase stability, which also means a high concentra-
tion of energy within very narrow parts of the spectrum (tens of hertz for
telegraph equipment, a few kilohertz for radiotelephone and a few megahertz
for radar equipment) [5].

The degree of biological activity of EMF is directly related to their magnitude
and frequency range. To describe the radiation, one must take into consideration
the integral power of all sources of radiation, types of emitting devices, nature
and mode of operation, duration of possible exposure, location of work places
in relation to radiation source and, to the extent this is feasible, several

other less important factors. The properties of EMF change as the distance from the radiation source increases. The nature of this change is related to oscillation frequency. At distances l, which exceed wavelength λ and dimensions of field source d or, more precisely, which satisfy both inequalities $l \gg \lambda/2\pi$ and $l \gg d^2/\lambda$, the EMF exists as formed spherical traveling waves. This is the wave zone. Here, there is a universal relationship betwen E and H: $E = 120\pi H$. In the wave zone, EMF can also be characterized by the flux of radiation density, $P = E^2/120\pi$. At frequencies below $3 \cdot 10^8$ Hz, intensities E and H are used as field characteristics, and above this level radiation energy flux density is used. This choice of characteristics was historically established in view of the distinctions of methods of measuring E and H at different frequencies.

At distances of less than $\lambda/2\pi$, in the so-called induction zone, EMF is not undulant and cannot be viewed as a spherical wave. At distances of less than d^2/λ and in the presence of objects that reflect EMR, diffraction phenomena are observed. In this zone there are numerous wave fluxes that spread in different directions. When added, these waves can intensify one another in some places and attenuate one another in others, forming diffraction maximums of field intensity and stationary waves [12].

The problem of exposure of crews and technical personnel is constantly on the mind of researchers; however, there is still no agreement as to the mechanisms of EMF effects on the body [13, 14]. EMR of different frequencies, which are physically the same, differ considerably in mechanisms of interaction with matter, in particular, with biological objects. In the future, development of the dosimetric approach such lead to introduction of a concept of relative biological effectiveness of absorbed energy common to the entire spectrum of radiations [15].
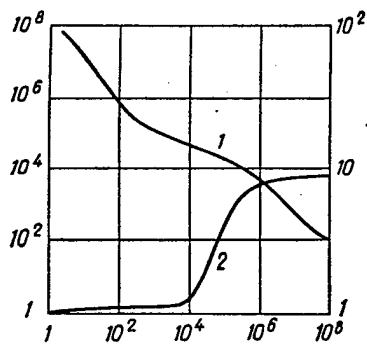
Figure 4.
Dielectric constant [permeability] (left, relative units) and conductivity of muscle tissue [right, $\sigma \cdot 10^{-3}$, $(\Omega \cdot cm)^{-1}$] as a function of EMF frequency
   X-axis, frequency (Hz)
   1) dielectric constant
   2) conductivity

The intracellular and intercellular media, which are based on an aqueous phase, have specific electric resistance of 100–300 Ω/cm and relative dielectric constant $\varepsilon_{rel} \approx 80$. Cell membranes have specific surface resistance of up to 10^5 Ω/cm^2, and their specific surface capacitance is 0.1–3 $\mu F/cm^2$ [16]. If such tissue is placed in a stationary electric field it becomes polarized. However, ion current will flow only in intercellular fluid, since with constant voltage of cell membranes, which are good insulation, there is reliable insulation of intracellular contents. In this case, migration of such large charged particles as cells and macromolecules is possible, i.e., electrophoresis.

The electric properties of biological tissues depend on the frequency of electromagnetic waves (EMW) (Figure 4), and they gradually lose the properties of dielectrics

and acquire those of conductors. Thus, at frequencies up to 10^4 Hz, only ionic tissue conductivity is possible. As a result of the high insulation properties of cell membranes, intracellular fluid is not involved in forming ion currents and, consequently, tissue conductivity is low. The oscillation periods are sufficient for the cell membranes to have time to be recharged at the expense of extracellular and intracellular ions. This means that the complete charge per period is large and tissue capacitance is considerable, i.e., dielectric permeability is high. However, with increase in frequency, capacitance resistance of membranes gradually diminishes, they undergo an incomplete recharge, intracellular tissue becomes involved in the process of formation of ion currents and conductivity of tissue smoothly increases, while dielectric permeability decreases.

The abrupt jump in specific conductivity at frequencies of 10^4-10^5 Hz can be attributed to the avalanche-like involvement of intracellular medium in the ion-producing process. Moreover, polarization of tissue molecules, mainly molecules of water, leads to appearance of displacement current, which increases substantially the full current in tissues.

At frequencies of 10^5-10^6 Hz, because of the minimal recharge of membranes, their capacitive and, at the same time, specific surface resistance drop, the cell contents become more actively involved in the process of formation of ion currents (i.e., tissue conductivity increases) and dielectric permeability diminishes. In addition, there is considerable increase in molecular polarization and, consequently, intensification of displacement currents it causes. As a result, the general current in tissues increases again.

With further increase in frequency, polarization of molecules and displacement currents start to dominate. We can observe resonance phenomena, since the characteristic frequencies of water molecules (both bound, "hydrated," and free water), as well as relatively free protein molecules are found to equal or be lower than the frequencies of the field to which they are exposed. The excited molecules begin an oscillatory motion, collide with unexcited molecules, transmitting their energy to the latter, which is used for chemical reactions, catalytic processes and are transformed into heat. As a result, there is drastic increase in conductivity. Thus, with increase in field frequency, there is change in properties of tissues, and the induced ion currents are gradually replaced by polarization of molecules [17].

The EMR energy absorbed by biological tissues is transformed into thermal energy. At frequencies up to about 10 MHz, the dimensions of the human body are small in relation to wavelength, and dielectric processes are minimal in tissues. For this reason, the human body may be considered to be a homogeneous conducting ellipsoid. One could expect resonance absorption of energy at a frequency of $f_{res} \simeq 12/L$, where L is the large axis of the ellipsoid (in cm) and f is frequency (in Hz) [18]. For man, $f_{res} \simeq 0.7 \cdot 10^8$ Hz. The field energy absorbed by an ellipsoid can be expressed as i^2/σ_{av} (W/cm^3), where i is ion current induced in the body (in A), σ_{av} is mean specific conductivity of the body $(\Omega \cdot cm)^{-1}$. If the longitudinal axis of the body is parallel to the lines of force E of the field, maximum current is induced in the body and its density (over the body's cross section) can be calculated using the following equations [17]:

$$j_E = 1{,}3 \cdot 10^{-13} \cdot f \cdot E, \ \text{A/см}^2,$$
$$j_H = 1{,}3 \cdot 10^{-11} \cdot f \cdot H, \ \text{A/см}^2.$$

In practice, designers and operators of electric equipment are already encountering the problem of making estimates of the hazard of electromagnetic radiation. Obviously, evaluation of this hazard should be made on the basis of existing standards for exposure. We can apply the following simplified procedure to analyze the hygienic situation in the presence of EMR: determination of physical characteristics of EMF; analysis of obtained characteristics; making a decision as to admissibility of the estimated EMR.

Determination of physical characteristics of EMF: In order to define the physical characteristics of EMF one has to evaluate the spectrum of radiation, intensities, exposure time and modes of operation of emitting units.

Analysis of determined characteristics: Assuming a priori that the biological effectiveness of EMF increases with frequency, analysis of the radiation spectrum should be made by the method of "competing frequencies." If the radiation spectrum is complex, it should be divided into several frequency intervals, and within each of them determination is made of maximum frequency f_1, f_2, ..., f_m and the corresponding percentile contribution n_1, n_2, ..., n_m of each interval. It is convenient to arrange the values of f_i in order of increasing frequencies and, consequently, in order of increasing biological activity of radiation. According to the standards in effect in our country for maximum permissible levels of exposure to EMF, it is recommended that the following low-frequency intervals be distinguished: electrostatic field (a), 0 ... 50 Hz (b), 50 ... $3 \cdot 10^6$ (c), $3 \cdot 10^6$ ... $3 \cdot 10^7$ (d), $3 \cdot 10^7$ ... $5 \cdot 10^7$ (e) and $5 \cdot 10^7$ ... $3 \cdot 10^8$ Hz (f).

In accordance with the "Sanitary and Hygienic Standards for Permissible Intensity of Electrostatic Fields" [19], personnel are allowed to remain in an electrostatic field with intensity of up to 60 kV/m for no more than 1 h. At the same time, with higher electric field intensities, air ionization may occur. For this reason, "Sanitary and Hygienic Standards of Permissible Levels of Air Ionization in Industrial and Public Buildings" [20] were approved. According to these standards, the minimum required quantity of positive ions/cm^3 air is 400, the optimum is 1500-3000, maximum permissible 50,000, for negative ions the figures are 600, 3000-5000 and 50,000, respectively.

We have GOST 12.1.002-75 for frequencies of 0 to 50 Hz, which specifies the standards for "Electric Fields of Commercial Frequency (50 Hz) and Intensity of 400 kV or More" [21]. According to these standards, man can spend no more than 5 min/day in an commercial frequency electric field with intensities of up to 25 kV/m.

In view of the fact that the biological effectiveness of EMF in the ranges considered increases with increase in frequency, one should use GOST 12.1.006-76 "Radio-Frequency (60 kHz-300 GHz) Electromagnetic Fields" [22], which allow man to be exposed in the course of the work day to EMF of 50, 20, 10 and 5 V/m for intervals (c), (d), (e) and (f). Standards have been set for the magnetic

component of the field for the ranges of $6 \cdot 10^4$, ..., $1.5 \cdot 10^6$ Hz -- 5 A/m, for $3 \cdot 10^7$, ..., $5 \cdot 10^7$ Hz -- 0.3 A/m.

According to the standards in effect in the USSR for EMR exposure levels, extrapolation formulas can be proposed for preliminary evaluation of the biological effect of radiation. Safe radiation levels from an electric field as a function of frequency, in the range of 0 to $3 \cdot 10^8$ Hz, can be determined with the following equation [23]:

$$E_{per} = 2 \cdot 10^4 \cdot e^{-1,03 \lg (f+1)}, \ V/M,$$

where f is EMF frequency, Hz [subscript "per" refers to permissible].

For the magnetic component, this parameter can be calculated with the following equation [24]:

$$H_{per} = 4 \cdot 10^4 \cdot e^{-1,55 \lg (f+1)}, \ A/M$$

Using these functions, determination is made of the safe radiation level at any frequency with a $\pm(30-50)\%$ margin of error. The following formula was proposed to relate permissible EMF intensities to exposure time [25]:

$$E_{per} = 31,5 - 4,12 \ln T,$$

where E is permissible level (kV/m) and T is exposure time (min).

As indicated by the data of the USSR State Committee for Standards and All-Union Scientific Research Institute of Physicotechnical and Radio Engineering Measurements, to analyze the mode of man's exposure to EMF it is expedient to introduce a conversion coefficient for intermittence of irradiation [26]:

$$E_{per} = k \cdot E$$

where $k = \dfrac{\text{duration of complete cycle}}{\text{operating time*}} \leqslant 10$

Decision making: This stage includes evaluation of permissibility of electromagnetic irradiation and (if necessary) use of additional means of protection such as permanent or portable shielding devices, as well as possible medical-epidemiological consequences.

In our opinion, it is necessary to include in the concept of "decision making" the aspect of subsequent search of experimental and clinical decisions as to conformity of existing standards to the degree of risk, to which the pilot and cosmonaut are exposed [27].

General evaluation of permissibility of electromagnetic irradiation ensues from the extent to which the parameters of its spectrum satisfy the inequality:

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*Translator's note: Alternate translation of denominator--operation starting time.

$$\sqrt{\sum_{i=1}^{m}\left(0,01 \cdot n_i \frac{E_i}{E_{i\,\mathrm{per}}}\right)^2} \leqslant 1,$$

where i is the number of the low-frequency interval singled out, m is the number of intervals, $E_{i\,\mathrm{per}}$ is the maximum permissible field intensity for the ith interval, E_i is the existing field intensity in the ith frequency interval and n_i is the percentile contribution of the ith interval to the integral radiation spectrum.

The following conclusions can be drawn on the basis of the above analysis of biological effect and hygienic situations related to static electric and low-frequency EMF associated with the work of aviation and space crews and service [technical] personnel.

1. Natural sources of EMF near and on the surface of earth (electric and magnetic quasi-static fields, atmospheric electricity and thunderbolts, solar and galactic radiation) generate intensities to which man has adapted rather well in the course of evolution.

2. The safety of low-frequency EMR from artificial sources can be evaluated (by analogy to the concept existing in radiobiology of "competing energies") on the basis of the method of "competing frequencies." The submitted formulas permit evaluation of the safety of low-frequency EMR. However, these formulas cannot be used for microwave EMF. When studying high-frequency radiation, a more detailed analysis is necessary of the distribution of absorbed energy in organs and tissues of biological systems, as well as consideration of a number of other factors.

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POSSIBLE USE OF ULTRASONIC BIOLOGICAL ECHOLOCATION AS A NONINVASIVE METHOD
OF EVALUATING INTRACRANIAL VOLUMES IN MAN

[Article by L. G. Simonov]

[English abstract from source] Potential applications of the
method of ultrasonic echolocation for determining intracranial
fluid volume relations are discussed. The data presented give
evidence that variations in the attenuation coefficient and pro-
pagation pattern of the ultrasonic signal may reflect changes in
both hemodynamics and intracranial pressure. Simultaneous in-
vasive investigations may help quantitate ultrasonic echolocation
results. The review shows that ultrasonic echolocation of the
brain can be used to determine variations in the intracranial
volume relations induced by simulated space flights and to make
well documented diagnoses.

[Text] Acute states appear in weightlessness, which are related to redistribu-
tion of body fluids. This is associated with a change in relations between
intracranial volumes (RIV) leading to elevation of intracranial pressure (ICP).
Evidently, ICP undergoes relative normalization in the course of adaptation.
Moreover, during spaceflights we cannot rule out cerebrocranial trauma and
development of other pathological states leading to a change in ICP. In view
of this, data on the state of RIV may acquire importance for monitoring of
adaptation processes, as well as for diagnostic and therapeutic purposes.

Under clinical conditions, quantitative invasive methods (inserting sensors
and catheters in brain tissue and ventricles) revealed that ICP may increase by
several times in the presence of brain lesion [1-6].

However, elevation of ICP is not necessarily the consequence of cerebral edema
or swelling. In a number of instances, elevation of ICP at different times is
due to an increase in blood volume in the brain [7], which is apparently due
to impairment of the mechanism of autoregulation, and the latter, as we know,
implies stability of hemodynamic parameters of the cranial cavity when arterial
pressure changes in the range of 150 to 60 mm Hg [8-11].

It is deemed possible to single out the following signs characterizing RIV changes in the presence of brain lesions, on the basis of data in the literature [12-14]: 1) ICP parameter (or intracerebral pressure) exceeds the range of 200-400 mm water (15-30 mm Hg); 2) the local cerebral blood flow (LCB) exceeds 20-80 ml/100 g/min; 3) more than 5% increase or decrease in blood supply to the brain; 4) change in amplitude and frequency of slow ICP waves related to hemodynamic changes; 5) appearance of pathological waves (plateau waves), i.e., uncompensated increase in blood in the cranial cavity for 5 to 20 min.

At the present time, there is no conventional noninvasive method that would permit at least qualitative evaluation of RIV changes.

We believe that the method of ultrasonic biecholocation could be the most promising method of noninvasive determination of RIV [15]. Ultrasound was first used for diagnostic purposes by Dussik [16]. Failures in passing continuous ultrasound through the skull (7, 17-21] led to development of the method of pulsed ultrasonic location of the brain, i.e., echoencephalography [9, 22-24]. Subsequently, several reports appeared, which dealt essentially with studies of displacement of the M echo (medial echo signal) and its diagnostic value in the presence of diverse brain lesions [25-29]. This direction of research, with use of diagnostic ultrasound, developed as a purely clinical direction.

Subsequent development of ultrasound techniques proceeded on the road of expanding the capabilities of the method and using it more extensively in functional tests. Thus, Japanese researchers, who examined the acoustic properties of the brain, conducted a series of experimental and clinical studies, and they found specific changes in the attenuation coefficient of ultrasound in the brain that were related to its functional state [30-34].

Naito et al. [32] established that there is diminished extinction [attenuation] of ultrasound in a brain with acute lesion, in the presence of edema.

Many researchers have been concerned with echolocation of the brain through the skull for diagnostic purposes [23, 36-51]. It was found that the medium interfaces (ventricles, blood vessels, etc.) could be defined on the basis of differences in acoustic properties of structural elements of the brain with the use of ultrasound [52-58].

The coefficient of attenuation was found to be 0.22 dB/cm at 1 mHz and 0.3 dB/cm at 2.25 mHz on animal brain preparations [30].

Naito et al. [32] studied changes in attenuation of ultrasound in the dog's brain following cerebrocranial trauma. At a frequency of 0.97 mHz, the attenuation parameter, which constituted 0.61 dB/cm in the initial state, dropped reliably to 0.41 dB/cm after trauma. The authors concluded that the ultrasonic reflection method can be used to detect cerebral edema in cases of cerebrocranial lesions. Iwata et al. obtained the same result [59]. Concurrent studies of parameters of ultrasonic attenuation, cerebral blood flow (Kety-Schmidt method), oxygen uptake and cerebrovascular resistance revealed a close relationship between blood volume and fluid content of brain tissue, on the one hand, and magnitude of attenuation of ultrasound in the injured

brain: ultrasound attenuation diminishes with decrease in blood volume and increase in fluid content of the brain. This conclusion was confirmed by the studies of Naito et al. [32], who demonstrated that the parameter of ultrasound attenuation (at a frequency of 2.25 mHz) increased in the brain from 2.0 to 3.0 dB against the background of bilateral ligation of the carotid arteries; however, it reverted to the initial level after 10-30 min.

Yoshimura et al. [34] also demonstrated that an increase in cerebral fluid content and elevation of venous pressure lead to decline of ultrasonic attenuation in the brain. At the same time, they found that, with increase in pressure of cerebrospinal fluid and decrease in cerebral blood flow rate, there is an increase in ultrasound attenuation.

Finally, body temperature affects ultrasound attenuation in the brain. Yoshimura et al. [34] determined that elevation of body temperature from 35 to 42°C (at 2.25 mHz) leads to decline of parameter of ultrasound attenuation to more than one-half. The opposite effect was obtained when body temperature dropped.

Thus, the main factors determining the degree of ultrasound attenuation in the brain are: sensor (generator) operating frequency, body (brain) temperature, cerebral blood volume and intracranial fluid volume. If a study is made at one specified frequency and constant brain temperature, all of the changes in ultrasound attenuation would be the consequence of changes in intracranial hemodynamic and hydrodynamic volume relationships, with concomitant change in ICP.

It is known that, under normal conditions, changes in ICP occur primarily as a result of changes in delivery [supply] of blood, whereas under pathological conditions they appear with development of edema or swelling of the brain. When conducting studies using functional tests, among other factors one must also take into consideration venous efflux, as well as the direction of hydrostatic pressure (if a man's position changes in space). Apparently, in the case of brief functional loads the main factor that causes change in attenuation of ultrasound is a change in delivery of blood to the brain, whereas with such prolonged factors as, for example, antiorthostatic [head down] hypokinesia, the change in this parameter could also be attributable to some change in amount of bound fluid in the brain.

The diagnostic capabilities of pulsed echoencephalography also began to attract the attention of researchers. As far back as 1955, Leksell [27] mentioned the pulsating nature of echo signals reflected from cerebral structures. There was a consistent change in amplitude of echo signals with change in heart rate. Jeppsson [8] observed a relationship between amplitude and phase characteristics of echopulsation and different pathological states of the brain, and he attributed the increase in amplitude of echo-signal oscillations to intracranial hypertension. Comparing echopulsation from the walls of the third ventricle with one-dimensional echoencephalography to concurrent EKG tracings, he demonstrated differences in phase relations of signals between healthy subjects and patients with signs of elevated ICP [60, 61]. Several authors had observed a relationship between amplitude of echopulsations and intracranial hypertension [62-65]. They found a reduction in time of elevation of the echopulsation curve (with elevation of lumbar spinal fluid pressure from 100

to 600 mm water) and shortening of interval between the start of the pulse wave of the carotid and start of increase in amplitude of echo signal in patients with elevated spinal fluid pressure, and they interpreted this pathological pulsation as the result of change in geometric boundaries between media differing in acoustic properties. At the present time, there are instruments that permit strobing a selected echo pulse and recording changes in its amplitude as a function of time.

I. A. Skorunskiy [66] and M. K. Bogolepov et al. [67] believe that occurrence of oscillations [fluctuations] in amplitude of echo signals is based on a change in geometry of interfaces reflecting ultrasound, due to the pulsating nature of delivery of blood to the brain. They found that there were marked pulsating fluctuations of echo signals in patients with hydrocephaly and elevated ICP. The authors believe that this is the consequence of a wide range of changes in volume of cerebral ventricles between systolic and diastolic periods, which leads to an increase in range of the angle of deflection of the ventricular walls. In the studies of Ye. Shevchikovskiy et al. [68], who used a direct (invasive) method, there was demonstration of increased pulsation in the spinal fluid system of the cerebrospinal cavity, against a background of elevation of spinal fluid pressure. The authors measured the amplitude of pulsations in the spinal fluid system through a needle introduced endolumbarly, before and after injection of 2 ml sterile saline. It was demonstrated that the same volume of saline (ΔV) injected endolumbarly at different initial levels of spinal fluid pressure elicits a different increment of this pressure (ΔP), namely, the higher the initial pressure (P), the greater the ΔP. The amplitude of pulsations as a function of changes in pressure was linear in these studies.

Although more than 100 years have passed since cerebral pulsation was discovered [63], the causes of formation of pulsed, respiratory waves and slower waves of hemodynamic origin are rather debatable.

Yu. Ye. Moskalenko et al. [69, 70] believe that the increase in amplitude of pulsation could be related to increase in amplitude of the central venous pulse or decreased tonus of cerebral arteries because of arterial hypoxia. Decrease in amplitude of pulsed pressure fluctuations in arteries of the base of the skull, increased tonus of cerebral vessels due to release of vasoconstrictive substances into the blood stream and drastic increase in venous blood in the cranial cavity could be causes of the decrease in amplitude of pulsation.

Speaking of the causes of increase in ampliutde of the echopulse wave against the background of elevation of ICP, it is opportune to mention the results of the studies of Oka et al. [71]. On the basis of their study of the possibility of diagnosing states associated with high ICP in neurosurgical patients, they concluded that the echopulse curve carriers information about intracranial hypertension. An increase in amplitude of the echopulse curve, decrease in time of elevation of the anacrotic part of the curve, as well as increase in interval between the start of systole on the EKG and time of elevation of the echopulse curve, contain information about changes in intracranial pressure.

The experimental studies of Oka et al. [71], which they conducted on dogs in order to confirm the clinical results, revealed that both artificial elevation

of intracranial pressure, with elevation of pressure in the cerebrospinal fluid system and elevation of ICP to 100 mm water, and creating an additional volume in the brain by means of blowing up a balloon in the intracranial space increase the amplitude of echopulsations in the third ventricle.

Particularly gross disturbances of echopulsation are observed in patients with lesions to the stem, which authors interpret [67] as a consequence of impairment of vascular self-regulating mechanisms of the stem. Most often, a drastic decrease in amplitude of echopulsations is the distinctive feature on echopulsograms obtained in comatose states associated with marked hypertension. After the patients come out of the coma, the amplitude of echopulsations increases, and signs of pathological pulsation appear.

Siedschlag [72] made simultaneous recordings of the EKG and echogram of 12 subjects without signs of elevated ICP and 100 patients with neurosurgical pathology who presented signs of ICP elevation in order to determine the capabilities of pulsation echoencephalography as a bloodless method of demonstrating ICP elevation. Analysis of differences between these groups was made with use of a criterion that takes into consideration the time of elevation of the echopulse curve and changes in interval between start of systole on the EKG and start of increase in signal amplitude on the echopulsogram. In all instances, different values for this criterion were obtained for patients with clinical signs of intracranial hypertension, as compared to healthy subjects. No relationship of the obtained data to level of blood pressure or pulse rate was demonstrated. The authors characterize pulsation echoencephalography as an absolutely harmless method, which can be used even under ambulatory conditions.

Thus, as shown by analysis of data in the literature, ultrasonic bioecholocation yields information about intracranial volume relations, and in order to make a more objective evaluation of observed changes in processes examined one must use both approaches discussed above: determination of magnitude of ultrasound attenuation and parameters of echopulsograms. The noninvasive nature of the ultrasound method and possibility of repeating the test many times for dynamic monitoring warrant the belief that bioecholocation can be used in studies related to determination of RIV when examining the effects of simulated spaceflight factors on man, as well as when examining cosmonauts for diagnostic purposes.

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EXPERIMENTAL AND GENERAL THEORETICAL RESEARCH

SAFETY CRITERION FOR PROTECTION OF PILOT'S HEAD AGAINST IMPACTS

[Article by A. S. Barer, Yu. G. Konakhevich and L. N. Sholpo]

[English abstract from source] In order to determine man's tolerance, clinical symptoms of craniocerebral injuries were compared with physical characteristics of impacts. A ranking scheme of clinical manifestations of craniocerebral injuries as applied to specific flight conditions was developed. With respect to the craniocerebral injury biomechanics, clinical data were taken under statistical study, which helped to evaluate impact critical parameters and to propose a graphic scheme that can be used to describe in detail the accident and to estimate the probability of injuries of various degree over the entire range encountered in aviation and clinical practice.

[Text] The main, though not the only, function of protective aviation helmets is to protect the pilot's head against impact in case of accidents. In assessing the protective properties of this gear, the choice of an adequate, medically validated criterion of the trauma hazard of a blow to the head presents a substantial problem.

Apparenlty, the state of the pilot's consciousness in the early minutes after sustaining a blow is a factor of paramount importance, which characterizes his ability to resolve the emergency situation on his own. The results of studies [1, 2] enable us to assess the severity and probability of consciousness disorders associated with cerebrocranial trauma as related to velocity and localization of impact. At the same time, consciousness is not the only important factor, since one must also take into consideration the need for the pilot to retain a certain level of work capacity, not only during the flight but for 2-3 days after the accident and possible landing in an unpopulated area should also be taken into consideration when developing rescue equipment. One must take into consideration the influence of remote studies on level of restoration of combat fitness [sic].

From this point of view, the clinical classifications of cerebrocranial trauma cannot be used directly since they are based on the results of special medical tests, victims who are in intensive care and they do not permit making an adequate evaluation of the quality of diverse protective gear [3, 4].

Thus, it is necessary to work out a special scale to assess the significance of cerebrocranial trauma from the standpoint of aviation practice and with consideration of use of protective gear.

As for the factor itself, its intensity had been estimated before [2] on the basis of velocity of impact of the human head with a flat barrier. Indirect evaluation of the impact had been made using the dynamic criterion of similarity of blow n [5, 6]. It was subsequently determined [7, 8] that, in the presence of integumental tissues of the head (unlike use of the isolated skull), parameter n is determined essentially by localization of the impact. The model of local deformations of the human head when a blow is sustained, which was described in [7], makes it possible to assess from the description of circumstances in which trauma was sustained (height of fall, localization, type of impact surface) the maximum contact force F_{max} and duration of anterior front τ_a of the impact pulse, which determine the nature of the skull's (particularly its base) biomechanical reaction to the blow. This would permit more precise determination of critical conditions of impact of the human head with a barrier.

This study was conducted in order to elaborate a criterion of man's tolerance of blows to the head as related to various exogenous conditions of the impact. Such a criterion could be used to evaluate gear to protect the pilot's head against blows.

This study, like the one reported in [2], is based on comparison of clinical manifestations of cerebrocranial trauma (according to data on file at the Institute of Neurosurgery, USSR Academy of Medical Sciences) to the physical parameters and localization of impact.

We used the correlations to the model of local head deformation upon impact to assess the parameters of the impact impulse (F_{max} and τ_a)[7, 8]. The initial velocity of the impact of the head and barrier (v_o) was evaluated on the basis of the description of conditions of trauma [1]. The resilience of the impact surface was characterized by parameter b, the value of which for different materials was obtained from [7, 8]. The equivalent [reduced] mass of colliding solids (M) was considered to equal the nominal mass of the head (m_n), which constituted 5.0 kg for men and 4.3 kg for women. Some instances of objects falling on the head were excluded, and for them the following was taken:

$$M = \frac{m_n \cdot m_f}{m_n + m_f}$$

(where m_f is the mass of a falling object, in kg).

Evaluation of consequences of a blow to the head as applied to specific conditions of flight practice was made according to the following parameters: state of consciousness immediately after the blow (A); general condition of the victim for 2-3 days after the blow (B) with consideration of the role of therapeutic measures or absence thereof during this period; final outcome of trauma, degree of general and professional rehabilitation (C). Table 1 lists the adopted gradations of factors A, B and C. Factor A was evaluated in 5 gradations (because of its particular importance to determining whether it is possible to save the pilot in an accident situation), while factors B and C had 3 gradations each.

Table 1. Scale for rating the consequences of a blow to the head

Factor	Grada-tion	Content
A	0	No impairment of consciousness immediately after blow
	1	Insignificant, brief impairment of consciousness: dim vision, vertigo, etc.
	2	Brief (2-3 min) impairment of consciousness or of adequate assessment of situation and behavior
	3	Profound impairment of consciousness for 2-3 min
	4	Profound impairment of consciousness for a longer time
B	0	No significant disturbances in general condition
	1	General disturbances, which do not preclude the possibility of survival in an isolated area with use of drugs in portable emergency kit for 2-3 days
	2	General disturbances that require qualified medical intervention within the first 2-3 days
C	0	Complete professional rehabilitation
	1	Absence of professional rehabilitation with complete restoration of health
	2	Disability

We introduced parameter D (from the English word, disease--illness, disorder, injury) for integral evaluation of the consequences of a blow to the head with regard to the listed factors, and its numerical value equals one-quarter of the sum of factors A, B and C. Thus, the value of parameter D was normed as 2, and a value of 0 meant that there were no adverse consequences of trauma, 1 and 2 referred to the bottom and top of the range of inadmissible states. The exception to this was referable to cases where death of the victim occurred as a result of trauma, in spite of rendering medical care. Then parameter D was given the maximum value (2) without considering the actual values of A and B.

Quantitative estimation of the interdependence of different parameters (F_{max}, τ_a, D) was made by the method of correlation and regression analysis [9]. The results of such analysis are listed in Table 2.

It was determined that the general condition of victims, evaluated with para-meter D showed a significant correlation to maximum contact force, and in all instances this correlation was linear. The overall coefficients of correlation (r) of parameter D to duration of anterior front (τ_a), as well as partial coeffi-cients of correlation ($r_{D\tau_a(F)}$), which were calculated with consideration of significant correlation τ_a/F, were found to be below critical tabulated values in all instances, for a confidence level of 0.95. For additional evaluation of significance of the special correlation between parameter D and time τ_a, we conducted a correlation analysis for samples where parameters D and τ_a were varied with virtually constant value of F_{max}. In all cases, the coefficients of correlation were below critical values.

Thus, it can be considered that the value of parameter D is determined essentially by the value of maximum contact force, and that it is virtually unrelated to

duration of the anterior front at a given contact force. This conclusion is in good agreement with our conceptions of biomechanics of cerebrocranial trauma due to blows to the head [2, 5, 6]. Indeed, the amplitude of system reaction to an exogenous factor is determined, for a rather broad class of dynamic systems, essentially by the amplitude of the input signal, and is little-related to its duration in cases where the lowest frequency of natural oscillations of the system are known to exceed the fundamental [base] frequency of the input signal.

Table 2. Characteristics of correlation between victims' condition and parameters of exogenous factor

Localization of blow	K	r	a_0	a_1	σ_0	σ_1	$r_{D\tau_a(F)}$
Occiput	D/F 139	0,380	0,0692	0,1734	0,0111	0,0350	
	D/τ_a 139	—0,013	—0,0043	0,8962	0,0287	0,0551	
	τ_a/F 139	—0,513	—0,2468	8,6911	0,0351	0,1388	0,202
Forehead	D/F 115	0,542	0,0283	0,1067	0,0031	0,0270	
	D/τ_a 115	—0,167	—0,0397	0,8111	0,0225	0,0542	
	τ_a/F 115	—0,566	—0,1298	6,7076	0,0181	0,2019	0,062
Temple	D/F 88	0,522	0,0761	0,3159	0,0008	0,1234	
	D/τ_a 88	—0,222	—0,0616	1,5376	0,0294	0,0631	
	D/F 88	—0,549	—0,2908	9,5111	0,0480	0,1946	0,091
Vertex	D/F 100	0,760	0,0282	0,2947	0,0021	0,0322	
	D/τ_a 100	—0,089	—0,0410	1,0161	0,0468	0,0644	
	τ_a/F 100	—0,494	—0,0781	5,0452	0,0136	0,1257	0,327

Key: K) number of cases
r) coefficient of correlation
a_0) absolute term of equations of linear regression
a_1) coefficient of proportionality
σ_0, σ_1) standard errors of parameters a_0 and a_1
$r_{D\tau_a(F)}$) partial coefficient of correlation

For probability forecasting of the pilot's condition after sustaining cerebrocranial trauma, the range of possible states was divided into three groups: unconditionally permissible, conditionally permissible in emergency situations and inadmissible. We consider blows to the head, after which the pilot retains virtually all of his ability for active action in an emergency situation, survival when landing in a desolate area and (provided medical care is given) complete professional rehabilitation to be unconditionally "permissible." In this case, parameter D does not exceed 0.25, i.e., only one of the factors—A, B or C (see Table 1)—may differ from zero and then not exceed 1.0. Conditionally "permissible" blows in an emergency situation are those after which the pilot retains, at least in part, the capacity to independently rescue himself from the emergency situation, survive when he lands in a desolate area with use of drugs from the portable emergency kit, even if rehabilitation does not occur after specialized treatment. In this case, 0.25>D>1.0. Finally, the inadmissible category is referable to cases of pilot death due to cerebrocranial trauma (regardless of when it occurs), as well as when there is no possibility of all of self-rescue from the emergency situation or survival wihtout immediate specialized medical attention.

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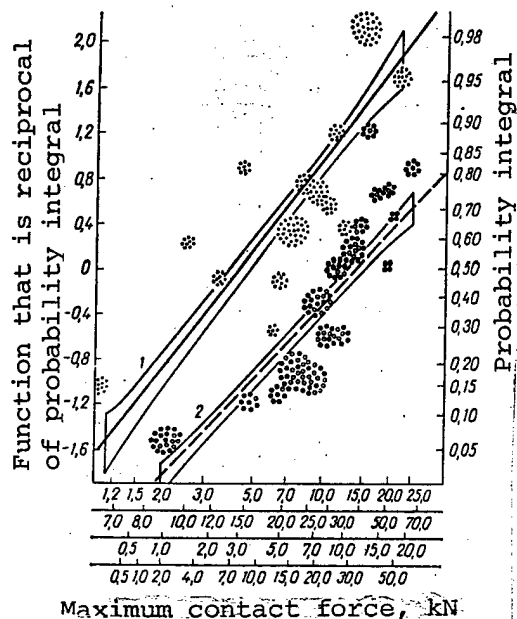
Figure 1.
Clinical data and regression functions
of probability of trauma in relation to
contact force
1) significant trauma
2) inadmissible trauma

For probabilistic evaluation of the
victim's general condition as a
function of F_{max}, we used, as before
[2], the "probit analysis" method
[9], with proportions of number of
cases for concrete values of force
as assessment of density of probability
of occurrence of a given state with
the given subrange of change in force.
The results of analysis revealed that
the correlation of the reciprocal
of probability integral as a function
of log F_{max} is linear and reliable for
the level of significance of P>0.99
for all studied localizations of the
blow, with both D>0.25 and D>1.0.

To reduce the confidence intervals
of the sought prognostic relations,
with consideration of the assumption
of similarity of the biomechanical
element of pathogenesis of cerebro-
cranial trauma of diverse localiza-
tion [2, 3, 4], as before [2], we
used regression functions between
the victims' condition and magnitude
of contact force (see Table 2) to
combine the results obtained with

blows referable to different localizations. By using these correlations, one
can obtain for each contact force and a given localization of the blow leading
to a certain state (D) the value of equivalent contact force (F*) for another
localization of the blow leading to the same state. The occipital region was
selected as the "generalized" zone of impact, for which there is the maximum
number of cases and equations for F* will be as follows:

$$F^* = \begin{cases} -1,7 + 0,42 \cdot F_{max} & \text{(forehead)} \\ 0,86 + 1,18 \cdot F_{max} & \text{(temple)} \\ 1,15 + 0,42 \cdot F_{max} & \text{(vertex)} \end{cases}$$

The distribution of experimental points for evaluation of probability of occurrence
of significant (D>0.25) and inadmissible (D>1.0) trauma is illustrated in Figure 1.
The solid and dotted lines refer to the corresponding lines of regression with
confidence intervals for P = 0.95.

These functions enable us to determine the critical values of contact force
leading to inadmissible cerebrocranial trauma with probability of 0.05 (which
corresponds to probability of 0.25-0.30 of occurrence of significant trauma),
which constitute 2.3-2.8 kN for blows to the occipital region, 9.2-10.7 kN to
the forehead, 1.3-1.7 kN to the temple and 3.0-4.0 kN to the vertex.

The actual values of F_{max} are not known in either clinical practice or when
analyzing circumstances of aviation accidents. For this reason, to calculate

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Figure 2.
Graphic chart for estimation of correlation between different parameters of blow and their effect on probability of trauma
1-4) blows to the occipital frontal, temporal and parietal regions
5) reduced mass
Г) ground
Д) tree
Б) cement
М) metal
СП) parolon (porous plastic) coated steel

them a model of local deformations of the human head associated with blows was developed, which utilizes the equations of semi-empiric impact theory [10] on the basis of our data on dynamics of living integumental tissues of the head [7, 8]. It is deemed inexpedient to submit here the cumbersome equations of this model, particularly since calculations with their use are quite time-consuming. The results of calculations enable us to offer a simplified graphic method of estimating the parameters with which we are concerned.

Figure 2 illustrates the plots of probability of trauma varying in severity as a function of F_{max} (top) combined with the plot of interrelationship between velocity of impact, reduced mass, initial energy of blow, characteristics of surface material and localization of blow (bottom).

In order to estimate F_{max} and probability of trauma in each concrete case, one must draw a perpendicular line from the point on the x-axis corresponding to initial velocity to the intersection with the curve of corresponding reduced mass, then draw a horizontal line from the point to the intersection with the curve corresponding to the selected material of impact surface and localization of blow. The vertical line of the point of intersection will traverse a point corresponding to maximum contact force on the axis corresponding to localization of the blow, while the intersection of this vertical line with the probability curves will give the value of probability of trauma with confidence intervals for P = 0.95. It can be shown that the proposed graphic scheme permits determination of the values of virtually all parameters of impact and probability of trauma differing in severity, relevant to aviation and clinical practice, for any localization of impact and collision surface.

Thus, the illustrated processing of clinical material, with consideration of biomechanics of the human head upon impact, made it possible to propose a scheme for ranking the clinical manifestations of cerebrocranial trauma in man and the parameters for assessing the pilot's condition after sustaining a blow to the head, determining the statistical relationship between the victim's state

and parameters of the impact, estimation of critical conditions of impact, proposal of a graphic scheme for calculating the parameters of impact and probability of trauma of different severity over virtually the entire range that is relevant to aviation and clinical practice.

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BALLISTOCARDIOGRAPHIC STUDIES DURING FOURTH MISSION ABOARD SALYUT-6 ORBITAL STATION

[Article by R. M. Bayevskiy and I. I. Funtova]

[English abstract from source] This paper presents ballisto-cardiographic examinations of the Salyut-6 fourth expedition crew members who showed variations in both the shape and amplitude of ballistocardiographic complexes. Ballistocardiograms (BCG) were recorded by means of a piezoelectric sensor with a sensitivity of 3 mV/cm·s^{-2}. The sensor weight was 30 g. The sensor was attached to the upper part of the iliac bone, near the body mass center. During ballistocardiography the ballistic forces in the head-to-feet direction were recorded. The examinations were performed preflight and on missions days 46, 71, 98, 133 and 175. Hemodynamic specificities of the right and left heart were determined with the aid of the breath-holding test. Measurements of BCG amplitudes were used to determine the kinetic effect of heart rate. The largest amplitude of BCG waves was seen on mission day 133. At this time period the systolic wave amplitude decreased during inhalation holding.

[Text] The ballistocardiogram (BCG) is a tracing of the pulsed microdisplacements of the body due to a change in position of its center of gravity as a result of ejection of blood from the ventricles into the aorta and pulmonary artery, phenomena of reactive recoil, changes in position of the heart in the chest, etc. Some of the mechanical energy imparted to the body is spent on overcoming friction and elastic recoil. If compelling forces were to be designated with an F, body inertia with $M\ddot{x}$, friction with $\beta\dot{x}$, force of elastic recoil with Dx, we would have $F = M\ddot{x} + \beta\dot{x} + Dx$, where M is body mass, β is coefficient of friction (damping factor), D is rigidity factor, $\ddot{x}$, $\dot{x}$ and x are acceleration, velocity and displacement, respectively. In order to reduce to a minimum the force of friction and elastic recoil, an ultralow-frequency (aperiodic) ballistocardiograph was developed [1], which records displacement of the body's center of gravity; however, the unwieldiness and complexity of the instrument limit its practical use.

Weightlessness is an ideal medium for measuring cardiovascular forces exerted on the body.

As we know, prolonged exposure of man to weightlessness leads to hemodynamic changes due to redistribution of blood to the upper half of the body, change in circulating blood volume and changes in afferentation. It is of the greatest scientific and practical interest to study the force and coordination of cardiac contractions, since no appreciable changes had been demonstrated in stroke and minute volumes, peripheral resistance and pulse rate in the course of flights lasting several months [2-4].

Methods

We used a "Pulse" type sensor to record the BCG in weightlessness [5]; it was developed and manufactured at the Institute of Applied Physics, USSR Academy of Sciences, in Gorkiy. We used a dimorphous piezoelectric element made of a thin polarized piezoelectric plate as the sensitive element. The element was soldered to a metal diaphragm [membrane], whose thickness and hardness were chosen so as not to have the solder plane exposed, to the extent this was possible, to tensile strain when the dimorphous element was deflected. A weight was attached to the diaphragm with a screw and served as the inertial mass. When the housing of the sensor moves, the weight acts on the piezoelectric plate with a force that is proportionate to acceleration, and a charge appears on its linings that is proportionate to deformation and, consequently, acceleration. The sensor has a sensitivity of 3 mV/cm·s^{-2}. The range of operating frequencies is 0.3-2000 Hz. The dimensions of the sensor are 26×26×11 mm and it weighs 30 g.

Since pulsed microdisplacements of a freely "soaring" body in weightlessness occur in three mutually perpendicular planes and there are rotatory movements about three axes, choice of location of the sensor and its orientation play an important part. The sensor was placed at the upper part of the iliac bone to record primarily the linear component of cardiovascular forces directed along the long axis of the body, i.e., near the center of gravity. The orientation of the sensor was such as to have the recorded forces directed perpendicularly to the plane of the diaphragm and housing. The sensor was contained in a foam-plastic block 30×30×30 mm in size, which had the appropriate markings. An elastic rubber strap with a metal buckle, which firmly contained the block with sensory in it, was used to fix the sensor on the subject's body.

In accordance with the technique for ballistocardiographic tests in weightlessness, while it was recorded the cosmonaut assumed a position, in which his arms were extended along the body and legs were extended along the body axis. The tracing was first taken during calm breathing, then with breath-holding in inspiration and expiration. To analyse the BCG, we determined the amplitudes (in mV) of HI, IJ, JK, KL and MN segments, as well as deflections according to Brown [6]. The Brown classification was modified to obtain more details about the changes in shape of the curve so that, in addition to values for degree of deflection [deviation] expressed in whole numbers, fractional values were also distinguished (i.e., 1.5, 2.5, 3.5). We used the equation for the second law of Newton to evaluate external cardiac function, its kinetic component, and force was expressed in newtons.

The first BCG tracing taken in spaceflight with the use of the above-mentioned sensor and method was made during the first mission aboard Salyut-6 orbital station on 23 December 1977. The recording was made by means of onboard medical

"Polynome-2M" equipment in the course of a combined examination of the cardio-vascular system [7]. BCG was recorded using the "Cardiocassette" instrument during the fourth mission in the Salyut-6 orbital station. The tests were made regularly, every month.

Results and Discussion

The Figure illustrates examples of BCG tracings before the flight and on the 46th, 71st, 98th, 133d and 175th flight days. Tables 1 and 2 list the results of analysis of obtained BCG's. According to Table 1, there were demonstrable dynamics, as well as some individual distinctions, when traditional amplitude analysis was made of BCG tracings and they were evaluated on the conventional Brown scale. There was a decrease in degree of deflection of the BCG in both cosmonauts by the 71st day, after which it began to increase. By the end of the mission, the BCG acquired the appearance of a chaotic curve with isolated, poorly identifiable complexes in the flight engineer (FLE). In the crew commander (CDR), the BCG also changed more appreciably at the end of the mission than at the start, but virtually all of the BCG complexes were demonstrable, although they were considerably altered. The amplitude of systolic waves in inspiration was usually wider than in expiration. This persisted in the CDR at all stages of the flight. In the FLE, systolic waves were smaller in inspiration than expiration on the 46th, 71st and 133d days of the mission. We were impressed by the tall diastolic waves in the FLE in expiration on the 46th and 175th days of the flight. Tall diastolic waves were demonstrable in the CDR in inspiration on the 98th and 175th flight days. Thus, the BCG recorded on the FLE during a long-term spaceflight presented the following distinctions: more significant changes in form of BCG at the end of the mission; distortion of BCG reaction to breath-holding test--increase in systolic waves in expiration on the 46th, 71st and 133d flight days; appearance of large diastolic waves in expiration at the start and end of the mission.
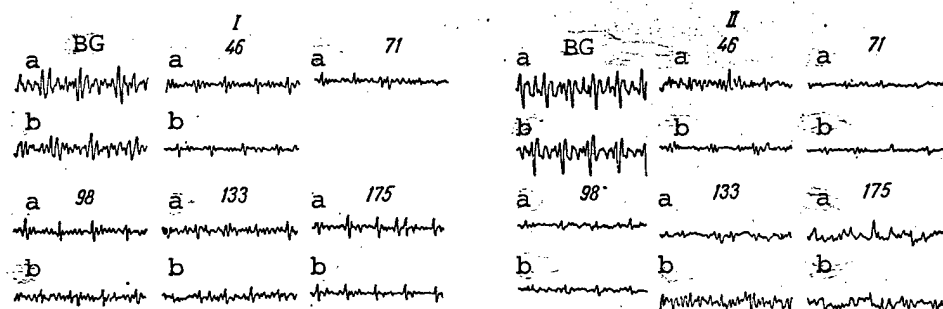
Examples of BCG tracings with breath-holding in inspiration (a) and
expiration (b) at different stages of flight, in CDR (I) and FLE (II)
of fourth mission in Salyut-6 orbital station
Key: BG) background

First of all, we should call attention to the correlation between amplitude and form of BCG obtained on the ground and in weightlessness (see Figure). The amplitude of ground-based tracings is 2-3 times wider than in flight. This

could be attributed to prevalence of elastic recoil forces and resonance oscillations of the body lying on a rigid surface, which are caused by them. For this reason, the shape of the BCG curve is appreciably related to recording conditions and body properties as an oscillatory element. For this reason, only a qualitative comparison can be drawn for ground-based and flight tracings.

Table 1. Amplitude segments (in mV) and degree of BCG deflection in crew of fourth mission aboard Salyut-6 orbital station

Day of flight	Deflection after Brown	Inspiration					Expiration				
		MI	IJ	JK	KL	MN	HI	IJ	JK	KL	MN
CDR											
Preflight	2,0	0,8	1,6	2,2	2,1	1,1	0,8	1,1	1,3	1,1	0,8
46	2,0	0,4	0,8	1,2	0,8	0,4	0,2	0,4	0,6	0,5	0,2
71	0	0,3	0,7	0,9	0,8	0,3	—	—	—	—	—
98	2,0	0,3	1,0	1,2	0,7	0,6	0,2	0,7	1,1	0,5	0,2
133	2,5	0,3	0,6	0,8	0,6	0,3	0,3	0,5	0,6	0,5	0,2
175	2,5	0,3	0,8	1,2	0,8	0,5	0,3	0,7	1,1	0,6	0,3
FLE											
Preflight	2,0	0,6	1,6	1,7	1,4	0,9	0,6	0,9	1,9	2,5	0,9
46	2,5	0,2	0,5	0,7	0,5	0,3	0,2	0,7	0,9	0,6	0,5
71	1,0	0,3	0,5	0,4	0,3	0,1	0,3	0,6	0,05	0,2	0,1
98	3,0	0,2	0,5	0,8	0,3	0,3	0,2	0,6	0,7	0,4	0,1
133	3,0	0,2	0,4	0,5	—	—	0,2	0,8	1,0	0,5	0,2
175	3,5	0,2	0,7	0,8	0,3	0,4	0,3	0,5	0,7	0,8	0,5

Table 2.
Results of estimating kinetic effect of cardiac contractions from results of analysis of BCG taken during fourth mission in Salyut-6 orbital station

Flight day	CDR			FLE		
	IJ_{max}, cm/s^2	mass, kg	force, N	IJ_{max}, cm/s^2	mass, kg	force, N
46	0,23	71,8	0,16	0,20	87,7	0,17
71	0,23	71,1	0,16	0,20	88,2	0,17
98	0,26	71,5	0,18	0,23	89,5	0,20
133	0,26	72,5	0,26	0,23	89,8	0,20
175	0,16	73,0	0,11	0,16	90,7	0,14

Table 2 lists the results of calculating kinetic energy of the ventricles in accordance with Newton's second law. The work performed by the heart consists of a static and kinetic component, i.e., counterpressure pumping of blood in the aorta and imparting acceleration to blood. We measure acceleration by means of the ballistocardiographic sensor and mass with a mass-meter that is onboard the orbital station. The estimates given in Table 2 are referable to maximum amplitude of segment JI during calm breathing. Segment JI was chosen because it reflects movement of blood over the ascending aorta, starting at the time the aortic valves open. As can be seen in Table 2, the force (in newtons) changes over the range of 0.11 to 0.26. This is 5-10 times less than the estimates of a number of authors [8-10]. There are different possible explanations for this. One of them is that it is possible for a change to take place in position of the maximum vector of cardiac force under the influence of displacement of blood to the upper part of the body. It is important to call attention to the fact that maximum force was observed in both cosmonauts on the 133d day of

the mission, whereas by the end of the flight there was a tendency toward decline of this parameter, which was more marked in the CDR.

In discussing our findings, it is necessary to bear in mind that the BCG reflects the activity of both parts of the heart simultaneously--the left and the right heart. The shape of the BCG depends on the correlation of forces and coordination, i.e., synchronism of contractions of each part. Impairment of hemodynamic balance could be due to different causes, including change in volume or velocity of blood influx, change in peripheral resistance or pressure in great vessels, change in functional properties of the myocardium of either part, change in physical properties of the displaced fluid--blood (absence of mass). Consequently, the improvement, virtual normalization of BCG complexes on the 71st day of the flight can be evaluated as resulting from achievement of hemodynamic balance under weightless conditions that are new to the body. Subsequent impairment of the established equilibrium could be due to the destabilizing effect of one of two factors--weightlessness or intensive physical training, and perhaps both of them.

The breath-holding test in ballistocardiography permits evaluation of the hemodynamic distinctions of the right and left heart. In inspiration, there is more intensive filling of the right chambers of the heart, the capacity of the pulmonary vascular system increases, there is less influx of blood to the left ventricle. The opposite is observed in expiration: influx of blood to the left heart increases, since there is a reduction in volume of veins in the pulmonary circulation, whereas filling of the right ventricle diminishes due to decrease in pressure difference between the thoracic and abdominal cavities. All of these phenomena occur in weightlessness apparently against a background of increased filling of pulmonary vessels, and the fact that the effect of increased systolic waves on the BCG is retained in the CDR during breath-holding in inspiration, as compared to expiration, is indicative of existence of the above-described mechanism of respiratory regulation of circulation.

A distorted systolic wave reaction was found in the FLE during the breath-holding test on the 46th and 71st days of the mission. Such a reaction could be the result of prevalence of hemodynamic activity of the left heart when there is increased filling of the pulmonary circulatory system. The increase in diastolic waves in inspiration on the 46th flight day confirms this opinion, since it can be related to intensified influx of blood to the left heart. According to ballistocardiographic findings, this relative hemodynamic prevalence of the left heart over the right reaches a maximum on the 133d day of flight. On the 175th day, the normal mechanism appears to be restored; however, the tall diastolic waves in expiration are indicative of possible development of qualitatively different correlation between forces of the left and right heart.

The maximization of the kinetic effect of cardiac contractions in both cosmonauts on the 133d flight day is of substantial interest. In both of them, this corresponded to a decrease in amplitude of systolic waves during breath-holding in inspiration. It is known that the ballistic effect of systolic ejection is considerably higher for the right heart than the left, since it

is proportionate to the square of velocity. This is attributable to the fact that the right heart functions against a low resistance of pulmonary circulation (diastolic pressure in pulmonary arteries is one-fifth to one-tenth the pressure in the aorta) and, consequently, the initial velocity of ejection of blood by the right heart is considerably higher. Thus, it can be assumed that a decline of kinetic effect of cardiac contractions is determined to a greater extent by the right heart.

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COMPARATIVE ASSESSMENT OF CIRCULATORY REACTION DURING WORK IN WEIGHTLESSNESS AND IN SALYUT STATION MOCKUP

[Article by V. G. Doroshev, N. A. Lapshina, Z. A. Kirillova, O. B. Kulikov, A. V. Kaliberdin and S. I. Ponomarev]

[English abstract from source] Comparative evaluations of circulation responses of 22 operators and 13 cosmonauts to simulated and real flights onboard Salyut station revealed significant differences. By the end of the flight cardiovascular responses of the operators showed signs of their increased conditioning, whereas the cosmonauts exhibited symptoms of circulation tension, which were particularly expressed during the first week and by the end of flight. Operators' activities in an orbital station mockup cannot be considered an adequate model for cardiovascular studies.

[Text] The cardiovascular system plays a large part in processes of adaptation to spaceflight conditions [1]. It is necessary to conduct control studies in mockups of space complexes in order to investigate circulatory reactions to factors associated with flight [2].

Our objective here was to make a comparative study of hemodynamics using "Polynome-2M" equipment on comsonauts in flight and operators working in space station mockups.

A total of 22 operators participated in 9 series of hemodynamic studies in mockups of manned orbital stations (MOS), which lasted 30 to 94 days.

Methods

As in our previous studies [3, 4], the parameters were recorded 4-6 h after nocturnal sleep at rest, once every 5-6 days. In the ground based studies conducted in mockups (MOS), the work program, daily cyclograms, work and rest schedule (WRS) of operators, as well as duration of their work in MOS mockups, diet and physical exercise were the same as in spaceflights.

Results and Discussion

Table 1 lists the dynamics of circulatory parameters according to averaged results of periodic medical examinations.

Table 1. Hemodynamic parameters of operators of Salyut MOS mockups (M±m)

Examination time	HR/min	AP, mm Hg				PWPR, m/s	SV, ml	MV, l	SPR, arbitrary units
		dia-stol.	mean	late-ral	end				
Background period	61±2	60±2	82±3	100±3	123±3	7,1±0,4	76±6	4,8±0,1	33±3
Week of study: 1	59±2	57±2	82±2	99±2	124±2	6,3±0,4	91±6	5,5±0,4	31±1
2	57±2	57±2	77±5	97±3	123±3	6,5±0,3	88±8	5,0±0,5	33±4
3	58±2	58±2	80±5	94±5	123±5	6,3±0,5	74±10	4,2±0,7	39±6
4	59±2	58±2	81±2	97±3	124±3	6,2±0,2*	87±5	5,0±0,4	31±2
5	57±2	57±2	81±3	99±3	124±3	6,0±0,3*	95±6*	5,5±0,5	32±2
6	56±2	53±1*	77±2	105±2	122±4	6,6±0,5	102±4*	5,7±0,2	26±1*
7	59±1	61±2	88±3	103±3	128±4	6,0±0,1*	119±6*	7,0±0,6	25±1*
8	60±1	58±2	83±2	97±5	118±3	5,8±0,3*	111±5*	6,6±0,4*	22±2*
Recovery period (1st week)	66±1	62±3	88±3	96±2	126±3	7,7±0,4	82±6	5,4±0,2	29±4

Key, for this and Table 2:
   n) = 22
  HR) heart rate
PWPR) pulse wave propagation rate over arteries of elastic type
  SV) stroke volume
  MV) minute volume
 SPR) specific actual peripheral resistance
  AP) arterial pressure
     *$P<0.05$ **$P<0.02$ ***$P<0.01$

Throughout the test period, the operators presented no complaints referable to their physical condition. HR and AP remained at close to the base level. Only in the 6th week of work in the mockup was there a reliable drop of AP_{min} [arterial pressure](by 12%). Pulse wave propagation rate over the aorta was slower than the base level at all readings, and the decline was reliable in the 4th, 5th, 7th and 8th weeks. From the 5th week on, there was an average of 40% increase in stroke volume. Minute volume exceeded reliably (by 35%) the base level in the 7th-8th weeks. Ejection period (EP) for the left ventricle presented a tendency toward increasing, and this was particularly evident from the 6th to 8th weeks, when stroke and minute volumes increased. Specific peripheral resistance dropped by 24%, as compared to base level, but conformed to nominal values.

Table 2 shows the general orientation of hemodynamic changes in the 13 cosmonauts who participated in spaceflights lasting 15 to 63 days.

We observed phases, which coincided with the dynamics of the cosmonauts' well-being, in dynamics of circulatory parameters. We were able to single out the following adaptive reactions of man to flight:

Table 2. Hemodynamic parameters of crew of Salyut MOS (M±m)

Examination time	HR/ min	AP, mm Hg				PWPR, m/s	SV, ml	MV, l	SPR, arbit. units
		dias.	mean	later.	end				
Background period	58±1	59±3	85±1	100±2	121±2	5,8±2	91±3	5,3±0,1	30±2
Week of flight:									
1	55±3	59±4	89±4	112±3***	137±3***	6,9±0,2***	107±7*	5,9±0,3	28±2
2	60±3	62±5	85±7	113±3***	151±12**	6,9±0,3***	94±6	5,6±0,2	27±1
3	59±2	57±5	93±4	111±8	135±4***	6,1±0,3	102±10	6,0±0,5	28±2
4	65±4*	57±2	83±1	107±2***	133±3***	6,8±0,3*	100±11	6,6±0,0	23±3
5	67±3*	62±2	86±4	108±7	131±7	6,6±0,3	102±8	6,7±0,8*	23±2
6	68±1***	56±4	84±3	105±1*	129±4	6,2±0,3	120±14*	8,2±0,5***	20±1
7	68±1**	63±2	83±3	110±3***	133±4***	7,0±0,3*	91±10	6,2±0,2	24±1***
8	67±2**	59±3	88±1	102±1	128±2*	6,8±0,2***	91±10	6,1±0,1***	25±2
Recovery period (first week)	67±1**	65±1*	91±1	111±2***	130±8	5,8±0,1	105±5***	7,0±0,2***	24±1

First stage: unstable reactions (1st week), when most cosmonauts reported discomfort due to weightlessness, associated with elevation of lateral and end AP, pulse wave propagation rate, increase in stroke volume and EP. These changes were probably due to redistribution of fluids with increase in central blood volume in chest organs [5].

The hemodynamic changes apparently reflected compensatory increase in tonus of resistive vessels directed toward raising central systemic pressure and preservation of circulatory homeostasis in the presence of elevated pressure in the system of the venae cavae [6].

Second stage: relative stabilization of reactions (2d week). This stage is characterized by a decrease in stroke and minute volumes, as well as reduction of ejection period to preflight levels with retention of arterial pressure level and pulse wave propagation rate established in the 1st week of flight, and relative decrease in heart rate. Such a correlation between hemodynamic parameters is apparently indicative of alteration of circulatory system function due to neurohumoral regulatory mechanisms referable to the concept of the Henry–Gauer reflex [7]. During this period, there was less rush of blood to the head of the cosmonauts, their general well-being improved and motor activity was increased.

Third stage: strained functions of circulatory system (from 3d week on). The typical findings at this stage were progressive increase in minute volume, higher values for heart rate, arterial pressure and pulse wave propagation than on earth that were not adequate to the resting state. The set of such concomitant signs as alteration of sleep and increased fatigability was indicative of development of asthenization and deconditioning of the cosmonauts' cardiovascular system. One should consider the more complicated flight conditions to be the chief cause of diminished adaptive capabilities: migration of sleep-waking cycle, unwise [unrational] work and rest schedule at certain stages of the flight, etc. [8-10]. There are data [11, 12] to the effect that such situations led to sleep disorders, poorer well-being and diminished work capacity in the first crews of Gemini, Apollo and Skylab spacecraft. Improvement of work and rest schedule, normalization of sleep-waking cycle and

allowing rest led to restoration of impaired functions. Of course, the stages of adaptation discussed do not reflect all elements of the body's adaptation to flight conditions. However, even relative determination of the duration of stages with a good or impaired adaptation process is important to practical medical support of spaceflights. It must be noted that the noted hemodynamic changes, discomfort and vegetovestibular disorders in some individuals during the 1st and 3d weeks of flight did not coincide. This is probably a reflection of individual reactivity [10, 13]. The reversibility of occurring changes, which did not always show a clearcut relationship to flight duration, stresses the need for examining individual adaptability to weightlessness and other flight factors.

After the flights, the cosmonauts presented substantial strain of the cardiovascular system at rest and reduction of its reserve capabilities in functional load tests [14-16]. Conversely, there was no decline of orthostatic endurance in operators of MOS mockups after termination of the studies, and physical work capacity was rated as being good [2, 17, 18]. These hemodynamic changes are indicative of an increase in level of physical conditioning of operators, which was attributable to the set of preventive measures that was used [19, 20]. This conclusion is confirmed by the fact that a marked circulatory reaction to a functional test was observed in unconditioned operators, unlike conditioned ones, during the first days of the study. In these tests, minute volume increased mainly due to increase in heart rate. By the end of the study, the increase in minute volume in response to the functional test was attributable chiefly to increase in stroke volume.

These results confirm the thesis that the cardiovascular system plays a large part in the process of adaptation to weightlessness [21, 22], whereas the phasic nature of changes in hemodynamic parameters is consistent with the conception of dynamic nature of human adaptation processes in the course of long-term spaceflights [10, 13].

The work of operators in MOS mockups is not an adequate enough model of space-flights for investigation of the human cardiovascular system.

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EFFECT OF IMMERSION HYPOKINESIA ON CHARACTERISTICS OF HUMAN EYE AND HEAD MOVEMENTS DURING GAZE FIXATION REACTION

[Article by Yu. V. Kreydich, A. A. Repin, V. A. Barmin and I. B. Kozlovskaya]

[English abstract from source] The effect of 7-day immersion hypokinesia on the coordination of eye and head movements during the gaze fixation reaction was investigated. The most distinct and persistent effect was an inadequate increase in the rate of eye counter-rolling that mismatched head movements. This reduced significantly the response time and accuracy: the time of gaze fixation lengthened appreciably and the number of positional errors grew considerably. These data suggest that in the oculomotor control system proprioceptive signals produce an inhibitory effect on the vestibular input.

[Text] Investigation of the effect of weightlessness on the nature of interaction of sensory systems is one of the principal problems of space biology. There is every reason to believe that a change in sensory interaction plays an appreciable part in the genesis of autonomic and motor disturbances, which are observed in space crews on the first day of a flight [1-3].

It is quite difficult to study the effects of weightlessness on earth because they cannot be reproduced entirely. One of the most recognized models of the physiological effects of weightlessness is immersion hypokinesia [4]. During immersion, elimination of support, as well as the drastic reduction of load on muscles, are associated with development of functional changes in a number of systems, which are similar to those observed in weightlessness. In particular, it was shown that brief submersion (up to 7 days) alters the characteristics of muscular afferentation in man in the same way as weightlessness [5, 6].

The functional approach to quantitative evaluation of parameters of complex reactions offers vast opportunities for investigation of the problem of sensory interaction in man. The mechanisms of these reactions have been studied comprehensively in acute and chronic experiments with animals. Of particular interest, in this aspect, is the fixation of gaze on an object that appears suddenly in the peripheral field of vision. The functional organization of

this reaction has been described in detail in several reports of studies conducted with primates [7-9]. It was shown that the speed and accuracy of gaze fixation are implemented by coordination of its three components (jump of the eyes in the direction of the target--saccade, turn of the head in the same direction, counterrotation of the eyes), which are based in primates virtually entirely on vestibular afferentation. Our preliminary studies [10-12] led us to assume that vestibular input plays an important part in expression of this reaction in man also. All of the foregoing enabled us to use the gaze fixation reaction as a test for assessing the functional state of the vestibular system and its interaction with other systems under conditions simulating the effects of weightlessness.

Methods

We tested 10 healthy males 26-38 years of age before and on the 2d, 3d, 4th and 5th days after 7-day immersion hypokinesia. The subjects were given a motor task: to fix their gaze on visual targets 1 angular degree in size as quickly and accurately as possible; these targets were exhibited on a white, U-shaped screen in three standard positions (20, 40 and 60°) on each side. The subject's standard eye and head position, in which he gazed at a central visual target, served as the zero reference point. The peripheral targets were presented soundlessly, in random order, which ruled out positional and time learning. Each test was preceded by 30-min dark adaptation.

In the course of the tests, we recorded eye and head movements in the horizontal plane. The eye movements were recorded on an electrooculograph (EOG), for which purpose silver chloride disk electrodes, 5 mm in diameter, were placed in the region of the lateral angles of the eyes. The EOG signal was fed into a universal amplifier with carrying capacity of 0 to 30 Hz at a time constant of 5 s. Head movements were recorded by a potentiometer [10] with use of bridge circuit, the output signal from which, which was proportionate to the turn of the head, was fed into the direct current amplifier. The eye and head movements were recorded on a general-purpose "mingograph EMT-34" tracer at the rate of 50 mm/s, which enabled us to assess the time parameters of movements with up to 10 ms margin of error. The trajectory of displacement of the gaze was plotted graphically, summing up the amplitudes of eye and head movement at 20-ms intervals.

In processing the data, we analyzed the time (latency period and duration), amplitude and velocity characteristics of eye and head movements, and shifting of gaze, as well as correlation between maximum speed of compensatory eye movements and head turn--amplification factor (AF) of the vestibulo-oculomotor reflex [10]. Accuracy of gaze fixation was determined from the number and magnitude of positional errors. The obtained data were submitted to statistical processing. Differences between mean values with $P \leqslant 0.05$ were considered reliable.

In addition, we used the galvanic test to assess the state of the vestibular system before and after immersion. The active electrode (anode) was placed in the region of the tragus and the silent one on the right wrist. Square-wave pulses lasting 100 ms from an ESU-2 stimulator were used for stimulation.

A stimulus eliciting contralateral deflection of the eyes to 4-6 angular degrees was considered the threshold stimulus.

Results and Discussion

Before immersion, the subjects performed the task of gaze fixation rapidly and accurately. Spatially, the timing of the fixation reaction was standard: first there was a saccade, then the head began to turn, then counterrotation of the eyes (Figure 1).
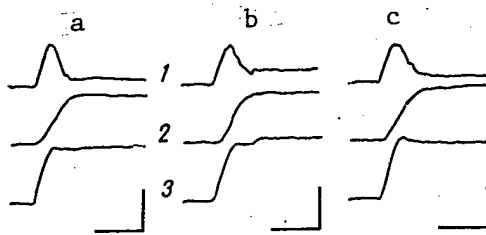
Figure 1.
Movements of the eyes (1), head (2) and shift of gaze (3) before (a), on the 2d (b) and 4th (c) days after 7-day immersion hypokinesia.

Movements are illustrated when gaze is shifted to light target at a distance of 60° from the center.
X-axis, time (500 ms); y-axis, amplitude (40°); BG--background

For targets in 20 and 60° positions, the latency period of the saccade constituted 240±24 and 275±35 ms, amplitude was 18±2 and 38±5° (i.e., less than the given angular position), duration 60±9 and 140±15 ms (Tables 1 and 2). The latency period (head turn in the direction of the target) constituted 290±28 and 300±28 ms (i.e., the turn started 50 and 25 ms after the start of the saccade), amplitude 20±7 and 43±5°, duration 305±37 and 415±89 ms, maximum angular velocity 110±28 and 185±40°/s.

Upon termination of the saccade, with the head still moving, there was appearance of compensatory counter-rotation of the eyes which stabilized the image of the visual object on the retina. Maximum velocity of compensatory eye movements conformed entirely to the velocity of head turn: AF was close to 1, fluctuating over a narrow range (from 0.96 to 1.00) for all target positions (Figure 2).
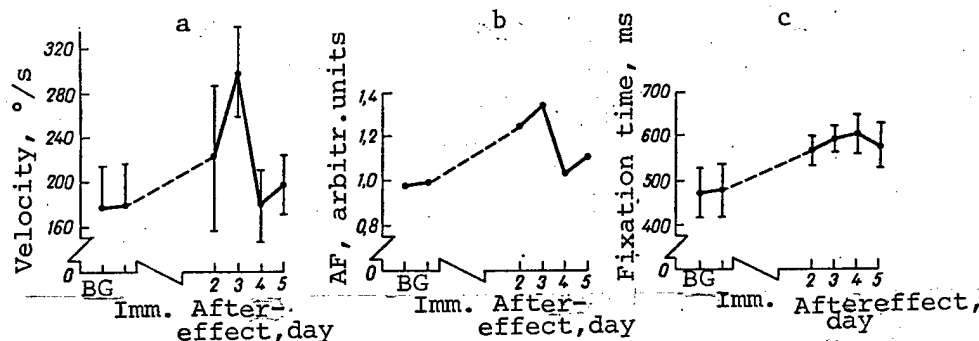
Figure 2. Dynamics of maximum speed of compensatory eye movements (a), AF (b) and fixation time (c) after 7-day immersion hypokinesia (Imm.). Graphic analysis of motion toward peripheral target, 60° to right

Fixation errors did not exceed 10%, mean error constituted ±5°. The errors were corrected by corrective saccades, which appeared 115-135 ms after the main saccade. Fixation time for 20 and 60° target positions averaged 320 and 460 ms, respectively (see Figure 2).

Table 1. Time parameters (M±σ) of elements of fixation reaction in background period and after 7-day immersion hypokinesia

Position of target	Day of test	Latency period, ms		Duration, ms	
		saccade	head turn	saccade	head turn
20°	Background	240±24	290±28	60±9	305±37
	2	240±26	300±33	60±11	335±55
	3	235±27	280±33	65±11*	390±40*
	4	235±23	275±29	63±9	370±39
	5	240±19	270±23	62±12	310±43
40°	Background	260±27	295±24	100±11	390±67
	2	250±27	300±26	104±16	400±58
	3	250±19	285±31	107±13	375±35
	4	255±23	285±31	104±14	435±43*
	5	265±17	295±26	110±11*	395±39
60°	Background	275±35	300±28	140±15	415±89
	2	255±21	300±15	155±8*	450±44*
	3	260±48	295±29	150±17	420±28
	4	270±31	295±26	145±13	445±36
	5	260±35	295±32	150±9	410±37

Note: Here and in Table 2—*P≤0.05, **P≤0.01, as compared to background.

Table 2. Amplitude and velocity parameters (M±σ) of movements of eyes, head and shifting of gaze before and after 7-day immersion hypokinesia

Position of target	Day of test	Amplitude, degrees			Maximum angular velocity, degrees	
		saccade	head turn	shift of gaze	compensat. eye movement	head turn
20°	Background	18±2	20±2	20±1,3	108±24	110±28
	2	19±4	23±4	20±1,0	135±46*	101±32
	3	23±7**	26±8*	21±1,1	155±31**	135±26*
	4	21±5	21±7	20±1,2	117±28	101±36
	5	19±7	18±7**	19±1,3	109±25*	107±27
40°	Background	30±4	33±3	40±1,5	148±36	150±40
	2	34±7	36±7	40±1,2	173±36	128±40
	3	38±6*	40±11*	40±1,4	230±33**	170±34*
	4	33±6	38±0,5	40±1,5	148±29**	131±37*
	5	34±6	34±10	39±3,1	158±31	145±29
60°	Background	38±5	43±5	60±2,5	179±36	185±40
	2	43±10*	52±14*	61±3,5	222±64	180±64
	3	45±6**	51±11*	60±1,5	297±39**	212±22*
	4	40±8	49±11	60±3,0	179±31	170±29
	5	40±8,5*	50±13	60±3,4	196±27	179±31

Immersion hypokinesia (for 7 days) did not impair the general pattern of the reaction (see Figure 1), but did alter appreciably the parameters of its components and their coordination.

There were changes in characteristics of saccades on the 2d and 3d days after hypokinesia: latency period was somewhat shorter after immersion, while amplitude and duration increased (see Tables 1 and 2). There was more change in

characteristics of head movements: appreciable increase in latency period, increase in amplitude and duration, significant increase in maximum velocity. There was an increase in speed of compensatory eye movements, which was substantially higher than the velocity of head turn, as a result of which the AF rose to 1.38 on the 2d day after immersion (see Figure 2).

The changes in characteristics of eye and head movements led to significant decrease in speed and accuracy of the test. There was appreciable increase in postimmersion fixation time (see Figure 2), the number and amplitude of positional mistakes increased: on the 3d postimmersion day erroneous movements constituted 80% or more; amplitude of errors ranged from 4 to 10°.

These signs were the most marked on the 2d-3d postimmersion days, and they leveled off by the 4th-5th day. As can be seen in Figure 2, the parameters of the fixation reaction were close to base levels on the 5th postimmersion day. However, even at this time, the velocity of compensatory eye movements was still higher than that of head turning, and AF remained elevated. Normalization of parameters of the reaction was associated with a decline to 20% in number of positional mistakes and reduction of fixation time, which, however, still exceeded the base value (see Figure 2).

Immersion hypokinesia also caused a distinct decline of thresholds of vestibulo-oculomotor respones to galvanic stimulation, which constituted 0.65±0.02 mA after immersion, versus 0.92±0.2 mA in the control (Figure 3).
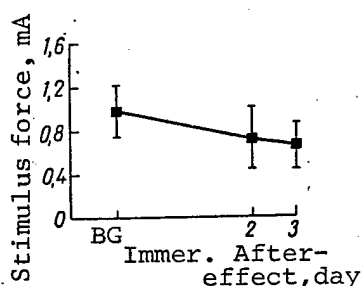
Figure 3.
Changes in thresholds of vestibulo-oculomotor respones to galvanic stimulation after 7-day immersion hypokinesia
  BG) background

These results confirmed data [13, 14] concerning involvement of the proprioceptive system in regulation oculomotor reactions and led us to make an assumption about the mechanisms of this involvement. The decrease in proprioceptive influx, due to lack of support, is associated with attenuation of all "vestibular" parameters of the reaction. The increase in velocity of compensatory counter-rotation of the eyes, reflected by elevation of AF, was the most marked and persistent effect of immersion. The decline of thresholds of vestibulo-oculomotor responses to galvanic stimulation was also indicative of heightened excitability of the vestibular system under these conditions. Attenuation [alleviation] of vestibular reactions after hypokinesia was also noted by G. I. Gorgiladze et al. [15], who tested the thresholds of occurrence of illusions using the galvanic test. These data warrant the assumption that proprioceptive cues have an inhibitory effect on the vestibulo-oculomotor reaction. Analogous interaction was described by Gernandt [16] in the systems of spinal control of motor reactions, in which both the proprioceptive and vestibular systems play an important role. In the opinion of Gernandt, the biological nature of this phenomenon is related to the fact that proprioceptive afferentation, which is younger in evolution, acquires dominant significance to motor regulation and inhibits the vestibular

system which is older. However, persistence of inhibitory interaction in the system of vestibulo-oculomotor regulation as well, where vestibular afferentation is definitely dominant, is indicative of the universality of the demonstrated phenomenon.

As shown by the results of these studies, immersion, which alters the characteristics of proprioceptive afferentation and has no direct effect on the vestibular system, impairs appreciably the performance of oculomotor tracking. It can be assumed that, in weightlessness, which alters appreciable the function of several afferent systems, functional disturbances of the oculomotor system could reach levels capable of lowering work capacity.

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CENTRAL CIRCULATION IN HEALTHY MAN DURING 7-DAY HEAD-DOWN HYPOKINESIA

[Article by V. Ye. Katkov, V. V. Chestukhin, E. M. Nikolayenko, S. V. Gvozdev, V. V. Rumyantsev, T. M. Guseynova and I. A. Yegorova]

[English abstract from source] The effect of 7-day head-down tilt (-15°) and lower body negative pressure on circulation and oxidative metabolism was investigated on 13 healthy male test subjects. For 7-10 days they had Swan-Ganz catheters implanted in the pulmonary artery and a special cannula in the radial artery. The most marked changes were seen in the pulmonary artery pressure (PAP) and central venous pressure (CVP) that varied in a phase-like manner. By the 7th hour of bed rest the PAP increased significantly; this was followed by increases in the total lung resistance and the right ventricle function, as well as by a slight decrease of renin and aldosterone. Beginning with bed rest days 2 or 3 the PAP and CVP declined and remained lowered, as compared to the pretest level, till the end of bed rest. The responses to LBNP tests changed by bed rest day 2. Possible mechanisms of the above changes at rest and during LBNP tests are discussed.

[Text] The period of acute adaptation to weightlessness or factors that simulate its effect (bed rest, immersion, etc.) continues to be the main concern of researchers. While the first few minutes and hours of exposure to simulation factors have been studied rather comprehensively using direct methods, there is no information in the literature about investigation of longer exposure (up to 7 days). Yet the study, under such conditions, of the main functional parameters of the right heart and pulmonary circulation (right ventricular filling pressure, function and contractility, pressure in pulmonary vessels, their resistance, etc.) could broaden our knowledge about the distinctions of adaptation of the cardiovascular system to gravity-related redistribution of blood to the intrathoracic region.

Our objective here was to investigate the effect of 7-day antiorthostatic [head down] hypokinesia (AOH) on central circulation and its reaction to decompression of the lower half of the body at different stages of immobilization.

Methods

Protocol: This study was conducted on 13 healthy male volunteers who had undergone a thorough medical examination (average age 33 years, height 179 cm, weight 77 kg, body area 1.94 m^2). Catheters were implanted in the pulmonary and radial arteries under hospital conditions. A background test was made 2 days before immobilization (postural tests and decompression of lower half of the body). Then 8 of the subjects were put on strict bed rest for 7 days with the body in antiorthostatic [head end of bed tilted down] position at 15°. The catheters were removed 1 day after AOH (recovery period).

Negative pressure to the lower half of the body (LBNP) was created by means of the Chibis suit, which was sealed at the level of the iliac crests. The functional test with LBNP was performed in the control, on the 2d, 4th and 7th days of AOH. At the start of the test, we examined the effect of the "transitory" period, during which pressure in the suit was lowered from 0 to -60 mm Hg within 2-3 min, with continuous recording of central venous pressure (CVP) and pressure in the pulmonary artery (PPA). All circulatory parameters were measured and blood samples taken for biochemical analysis at the "stable" stage (LBNP -- 30 mm Hg for 10 min).

Catheter implantation: A two-way Swan-Ganz catheter, with thermistor and balloon (model 93A-131-7F) was introduced into the pulmonary artery through the subclavian vein which was punctured under local anesthesia. Catheterization was monitored roentgenologically with use of the pressure curve. The catheter was positioned in such a way as to have the distal opening (and thermistor) in the trunk of the pulmonary artery and the proximal one in the region of the right atrium. It was flushed once a day, after which it was filled with heparin solution, closed with a plug and taped to the chest near the insertion site. The catheter remained in the pulmonary artery for 10 days, except for 3 subjects who participated in the study twice, in whom it remained for 17 days. Concurrently with catheterization of the pulmonary artery, a special cannula (Medicut, Sherwood Med., Inc.) was used to puncture the radial artery, in which it was left for several days.

Data recording: CVP, PPA and pressure in the radial artery were measured with electric manometers No 746, which were kept on the level of the right atrium throughout the study and recorded parameters on a Mingograph EM-82 (Siemens-Elema) automatic tracer.

Pressure in the esophagus was measured with a differential manometer (KIAG) through a catheter with a latex balloon which was placed (under x-ray monitoring) in the region of the left atrium. In spite of the fact that there is some difficulty in recording this parameter, data in the literature indicate that it reflects rather accurately changes in intrapleural pressure, in both horizontal position and postural tests [1, 2].

Cardiac minute volume was determined by the heat-dilution method [3] using an Edwards Lab. computer (model 9520), with concurrent recording of thermo-dilution curves. At each stage of the study, minute volume was determined 2-3 times, synchronizing the time of injection of saline in the right atrium with the phases of the respiratory and cardiac cycles.

On the basis of the thermodilution curve, calculation was made of blood content of the right heart (i.e., from the site of injection of tracer to the thermistor located near the pulmonary artery valves) and mean transit time of passage of tracer in this segment. The dynamics of changes in end diastolic and end systolic volumes, as well as ejection fraction, were assessed according to stages of flushing out of the tracer from the right ventricle.

Resistance of pulmonary vessels was calculated as the ratio of difference between mean and end diastolic pressure in the pulmonary artery, which was close to the pressure in the left atrium in head-down position [4], to cardiac index. The dynamics of mean rate of build-up of pressure in the right ventricle (dp/dt_m) were determined as the ratio of pulmonary artery valve opening pressure to time from R wave of the EKG in the second standard lead to start of pressure elevation in the pulmonary artery, in the belief that the duration of the period of asynchronous contraction does not change. Transmural pressure in the right atrium and pulmonary artery was determined as the difference between pressure in these regions and intraesophageal pressure. Cardiac and stroke indexes, function of the right ventricle and blood oxygen content were determined with the usual formulas.

Plasma renin and aldosterone activity was measured by the radioimmune method using commercial packs of the Sorin firm. Acid-base equilibrium and gas composition of blood were determined with an AVL 940 (AVL Bio-med. Lab.), oxygenation was measured with an OSM-2 hemoxymeter (Radiometer).

The results were processed on a computer, and Student's t criterion was used for statistical analysis.

Results and Discussion

A series of studies (n = 6) was conducted before the start of AOH to examine the effect of "acute" postural factors on transmural pressure in the right atrium and pulmonary artery. The change from orthostatic to horizontal position was associated with about the same elevation of CVP, PPA and intraesophageal pressure (Figure 1). As a result of this, transmural pressure in the left atrium and pulmonary artery remained relatively constant for the first 5-10 min after changing from orthostatic to horizontal position.

During 7-day AOH, we measured daily (and almost hourly on the 1st day) the parameters of circulation, acid-base balance and oxidative metabolism (n = 8) (Table 1). Throughout the AOH period, there was no appreciable change in mean tracer transit time, end diastolic and end systolic pressure in the right ventricle of the heart, its ejection fraction or parameters of acid-base equilibrium. The most noticeable changes were seen in CVP and PPA, which were phasic (Figure 2).

Figure 1.
Change in absolute (a) and transmural (b) pressure (in mm Hg) in different parts of the intrathoracic region with change from vertical to horizontal position
1) in esophagus
2) in pulmonary artery
3) in right atrium

Table 1. Parameters of circulation and oxidative metabolism of mixed venous blood during 7-day AOH

Parameter	Control	Day of AOH												Recovery period
		1						2	3	4	5	6	7	
		0 h	1 h	2 h	3 h	5 h	7 h							
CVP, mm Hg	4,3±0,7	3,9±0,3	3,6±0,5	4,6±0,5	4,4±0,9	3,8±0,3	3,8±0,7	2,5±0,6	1,8±0,6*	2,1±0,7	0,9±0,4	1,2±0,5	0,8±0,6	3,0±0,4
PPA, mm Hg: S	20,5±0,7	20,1±1,1	18,9±0,9	21±1,7	21,4±1,9	23,9±1,6	25,6±1,8*	20,3±1,1	17,7±1,1*	17,7±1,1*	17,8±1,1	16,9±1,6	16,9±1,6	21,5±1,5
D	9,6±0,6	10,3±0,6	10,0±0,5	10,8±0,7	11,6±1,0	11,8±0,7*	11,9±1,0	9,0±0,7	7,4±0,9	7,4±0,9	7,1±0,9*	7,1±1,2	6,1±0,8	9,0±0,9
M	13,6±0,6	13,6±0,6	13,0±0,4	11,4±0,9	15,1±0,1	16,1±0,8*	16,8±1,2	12,9±0,8	11,0±0,9*	10,9±0,6*	10,9±0,8	10,1±0,9	9,8±1,0	13,2±0,8
RVF, kg-m/min	1,4±0,1	1,5±0,1	1,4±0,1	1,4±0,1	1,5±0,1	1,7±0,1	1,9±0,2*	1,3±0,1	1,2±0,1	1,1±0,1*	1,2±0,1	1,1±0,1	1,0±0,1	1,7±0,2
dp/dt m/s, BV mm Hg/s	101±9,7	100±11,5	89±9,9	88±12,4	86±8,8	99±14,2	95±13,8	82±7,9	66±10,0*	75±7,5	77±6,6	74±6,5	61±6,3	94±4,8
BV, ml/m²	250±13	253±12	247±6	243±13	236±11	250±12	260±12	245±18	256±21	240±19	252±28	248±23	252±18	298±34
CI, l/min/m²	3,9±0,1	4,1±0,2	4,0±0,2	3,7±0,1	3,8±0,2	3,8±0,1	4,1±0,2	3,9±0,1	4,0±0,1	3,7±0,2	4,1±0,3	3,8±0,1	3,7±0,1	4,7±0,2*
SI, ml/m²	57,7±1,0	56,5±1,2	58,6±2,4	55,9±2,0	55,1±1,8	54,8±1,1	59,8±1,4	56,3±1,3	56,6±1,5	54,5±2,6	55,6±3,2	51,9±1,9	53,5±1,7	59,5±2,1
HR/min	69,0±2	73,0±0,3	69,0±2	67,0±2	70,0±0,6	75,0±4	69,0±4	69,0±3	70,0±2	68,0±2	74,0±4	73,0±2	69,0±1	79,0±3*
AP, mm Hg: S	139±5,1	133±2,5	135±2,2	137±3,8	135±3,5	129±3,6	132±6,3	—	—	—	—	—	127±3,6	—
D	76,2±3,0	73,7±3,1	77,3±1,6	84,4±4,2	79,4±3,4	77,0±3,6	79,7±7,0	—	—	—	—	—	75,0±3,7	—
M	97,4±1,4	94,6±2,0	94,5±1,1	100,6±3,5	97,4±3,0	93,5±2,8	95,5±6,5	—	—	—	—	—	91,0±2,1*	—
pO₂, mm Hg	42,0±0,9	41,6±0,9	42,6±1,1	41,3±0,8	40,5±1,0	40,7±0,6	39,8±1,5	42,9±1,1	42,8±1,4	41,9±1,1	44,2±0,9	45,9±0,9	44,5±1,3	47,6±1,3*
HbO₂	77,5±2,1	76,9±1,3	77,1±1,7	76,2±1,1	72,8±1,4	74,1±1,4	73,3±1,4	77,9±1,2	77,9±0,8	76,0±1,2	78,5±1,0	79,6±1,2	77,2±1,0	80,2±1,2

Key for this and Table 2:

    S) systolic pressure
    D) diastolic
    M) mean
  RVF) function of right ventricle of the heart
   BV) blood volume in right heart
   CI) cardiac index

    HR) heart rate
   pO₂) oxygen tension
    SI) stroke index
    AP) pressure in radial artery
  HbO₂) oxygenation of hemoglobin

*P<0.05, as compared to the control.

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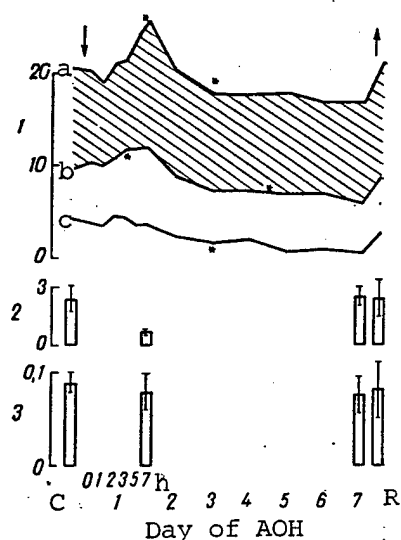
Fiugre 2.

Changes in intrathoracic pressure (mm Hg), renin ($\mu g \cdot \ell^{-1} \cdot h^{-1}$) and aldosterone ($nmole^{-1} \cdot \ell^{-1}$) activity during 7-day AOH

1, a-b) PPA (crosshatched area)
    c) CVP
2, 3) renin and aldosterone activity
   C) control (base levels)
   R) recovery period
0, ..., 7--hours after start of AOH
*P<0.05

Starting in the 2d-3d hour of AOH, PPA rose, particularly systolic, in 6 out of 8 cases, and it reached a maximum by the 5th-7th h of hypokinesia. This was associated with 22% increase in resistance of pulmonary vessels and an increase in function of the right ventricle. This period was characterized by a tendency toward decrease in plasma renin and aldosterone activity (n = 4) (see Figure 2). In most cases, the subjects developed unpleasant subjective sensations during the first hours of AOH (blood rushing to the head, headache, nasal congestion, etc.), which diminished significantly or disappeared on the 2d day of AOH. By this time, PPA reverted to the base level, while CVP was below the initial level. By the 3d day, CVP and PPA, mean rate of pressure elevation in the right ventricle (dp/dt_m) and function thereof were lower than base levels and remained so to the end of the hypokinetic period.

In the recovery period, we observed a marked increase in heart rate and cardiac index, CVP and PPA rose close to base levels, O_2 tension in mixed venous blood and oxygenation thereof increased appreciably.

Figure 3 illustrates the changes in PPA and CVP in the "transient" periods of LBNP at different stages of AOH: Table 2 lists the parameters of circulation and oxidative metabolism recorded in the "stable" state. From the submitted results, it is apparent that the circulatory reaction to LBNP changed somewhat as a function of duration of AOH, and this was more noticeable under the effect of dynamic modes.

The series of tests conducted before AOH revealed that the change from orthostatic to horizontal position was associated with approximately the same increase in CVP, PPA and pressure in the esophagus, which reflects intrapleural pressure. As a result, transmural pressure, i.e., the adequate stimulus for stretch receptors of these regions, remained relatively constant. Evidently, it also did not change in the left atrium, since elevation of pressure in it upon changing to horizontal position was about the same as in the right atrium [4]. Our findings are consistent with data in the literature [1, 2, 5, 6], according to which the vertical pressure gradients of the pericardium, pleural cavity, atria and great intrathoracic veins change under the influence of postural factors like in a simple hydrostatic system, as a result of which postural changes are not associated with change in transmural pressure in this region [1, 5, 6]. These changes differ basically from those that appear upon submersion in an immersion tank up to the neck, when pressure in the esophagus rises by 4-5 mm Hg

Figure 3.

Changes in PPA (I, mm Hg) and CVP (II, mm Hg) under the effect of dynamic LBNP modes at different stages of AOH. X-axis, LBNP level
1) control (base state)
2-4) 2d, 4th and 7th days of AOH

and in the right atrium by 12-18 mm Hg, i.e., transmural pressure in the atrium rises 8-13 mm Hg [7]. Thus, the impression is gained that ordinary postural factors are not associated with appreciable change in transmural pressure of great veins of the intrathoracic region and cardiac cavities, which means they do not stimulate the stretch receptors of these regions. However, when duration of immobilization is increased, the situation in the pulmonary artery--left atrium system could change significantly.

The most typical aftereffect of AOH in the first few hours was marked elevation of PPA, which was observed against the background of relatively stable CVP. These parameters usually changed in the same direction with brief postural factors and for this reason their "dissociation" is apparently due to adaptation to long-term gravitational redistribution of blood to the intrathoracic region.

It should be noted that we had also observed this distinction in our previous studies, which were methodologically less successful [8]. In the presence of acute catheterization and concomitant factors (premedication, local anesthesia, etc.) it was found that systolic pressure in the right ventricle (and, consequently, in the pulmonary artery) rose, whereas filling pressure (CVP) did not change by the 3d hour of AOH (-20°). There are no data in the literature concerning changes in PPA caused by implantation of catheters during longer term of AOH. As for CVP, Nixon et al. [9] failed to demonstrate statistically significant changes therein in the course of 24-h ANOH (-5°).

Among the various functional causes of elevation of PPA, there could be an increase in minute volume of the heart, increase in pulmonary vessel resistance and blood volume in them, change in elasticity of the left heart, etc. However, in this study, the increase in total pulmonary resistance was one of the prime causes of elevation of PPA, and this occurred apparently on the order of a Kitayev reflex in order to maintain a constant pressure in pulmonary capillaries, which is one of the most important prerequisites for preventing pulmonary edema. Perhaps, it is expressly because of involvement of this mechanism that no increase was observed in lung tissue volume by the 6th h of AOH (-5°) [9, 10]. The possibility cannot be ruled out that this reaction was also directed at preventing further elevation of pressure in the left atrium, which plays an important part in regulation of hemodynamics in the systemic circulatory system [11].

We demonstrated previously that end diastolic pressure in the pulmonary artery was virtually the same as mean pressure in the left atrium (end diastolic

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pressure in the left ventricle of the heart) in healthy man in antiorthostatic position [4]. In other words, the demonstrated changes indicate that, for the first hours of AOH, transmural pressure in the left atrium and, particularly, pulmonary artery rose, whereas it did not change in the right atrium. It is a known fact that elevation of transmural pressure in the left atrium--pulmonary artery segment could have an appreciable effect on fluid-electrolyte metabolism and renal function (Henry-Gauer reflex). Thus, Henry [12] demonstrated that 15 cm water increase of transmural pressure in this region increases diuresis, and in 50% of the cases it was 2-5 times greater than base levels. Indeed, as shown by our results, the demonstrated decrease in renin-angiotensin-aldosterone system activity and, consequently, increase in excretion of Na and fluid by the kidneys could be related primarily to elevation of pressure in the system of the pulmonary artery, particularly the minutest veins.

Table 2. Parameters of circulation and oxidative metabolism of mixed venous blood during LBNP of -30 mm Hg at different periods of AOH

Parameter		Control	Day of AOH		
			2	4	7
CVP (mean), mm Hg		—1,0±0,4	—1,1±0,4	—0,6±0,3	—0,7±0,3
PPA, mm Hg:	S	10,0±0,9	11,7±0,8	12,4±1,1	11,9±1,1
	D	4,0±0,6	4,5±0,7	4,5±0,8	3,8±0,8
	M	6,0±0,6	7,1±0,6	7,3±0,8	6,6±0,7
RVF, kg-m/min		0,5±0,04	0,6±0,07	0,6±0,07	0,5±0,06
BV, ml/m^2		195,6±6,8	176,8±7,1	169,5±9,9	198,8±21,3
CI, l/min/m^2		2,9±0,1	2,9±0,1	2,8±0,1	2,8±0,08
SI, ml/m^2		37,4±1,3	35,4±2,0	35,4±0,7	35,2±1,1
HR per min		78,0±3,0	83,0±5,0	80,0±3,0	80,0±2,0
AP, mm Hg:	S	134,0±5,8	—	—	124,5±5,0
	D	81,2±2,2	—	—	83,3±3,1
	M	97,3±2,1	—	—	95,5±1,8
pO$_2$, mm Hg		38,1±1,1	40,1±1,5	38,6±1,0	40,3±0,8
HbO$_2$, %		69,0±1,5	71,4±2,0	70,0±1,1	71,2±1,1

It should be noted that the dynamics of pressure elevation in this region that we recorded coincided well in time and intensity with changes in parameters of fluid-electrolyte and hormonal metabolism demonstrated by other authors on the 1st day of AOH. In particular, Nixon et al. [9] demonstrated that, starting in the 2d-3d h of AOH, there is a tendency toward decrease in plasma renin activity and aldosterone activity, as well as that of antidiuretic hormone. By the 4th-6th h of AOH, these changes were close to a maximum level, whereas the urine Na/K ratio increased appreciably. After 24 h, these parameters reverted to the initial level; however, circulating blood volume diminished by 400-500 ml as a result of increased diuresis. According to Kirsch et al. [13], the known correlation between CVP and circulating blood volume inherent in rapid changes in the latter [14] could also apply to longer change in fluid homeostasis. According to these conceptions, it can be estimated that, in our study, circulating blood volume diminished by about 350 ml by the 2d day of AOH.

Under such conditions, the decrease in central blood volume was apparently due to decrease in blood volume in the lungs, since there was virtually no change in blood volume of the right heart.

As we demonstrated previously, LBNP of -30 mm Hg elicits marked changes in venous pressure of the intrathoracic region, the levels of which are close to those recorded in orthostatic position [15]. Moreover, with this mode of LBNP, it leads to decline of blood volume in the right heart, end diastolic and end systolic volumes thereof by 22, 19 and 9%, respectively, whereas the ejection fraction has a tendency toward increase, while mean tracer transit time in this region does not change. Our findings are very consistent with the data obtained by Rapaport et al. [16] during orthostatic tests. Using the thermo-dilution method, they demonstrated that, in vertical position, end diastolic and end systolic volumes of the right ventricle diminished by 17 and 4%, respec-tively, whereas the ejection fraction increased somewhat.

There was some change in circulatory system reaction to LBNP during AOH, and this was particularly evident with use of dynamic modes. These changes arose already on the 2d day of AOH and were observed to the end of the period of immobilization. They could be due to relative hypovolemia, which already in the base state was associated with decline of CVP adn PPA and, perhaps, transmural pressure in the decompression region. Moreover, change in the usual correlations between transmural pressure and venous volume, i.e., change in extensibility of veins, was apparently significant.

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DISTINCTIONS OF CARDIOVASCULAR REACTIONS IN IMMEDIATE LBNP AFTEREFFECT PERIOD

[Article by L. Ya. Andriyako, V. G. Voloshin and V. A. Degtyarev]

[English abstract from source] Circulation variations during
LBNP immediate aftereffects were investigated. The test subjects
with different test tolerance showed dissimilar cardiovascular
responses. The lack of reflex bradycardia in the test subjects
with reduced LBNP tolerance gives evidence that their regulatory
mechanisms are insufficiently reactive; this is manifested during
aftereffect of low LBNP (up to -40 mm Hg).

[Text] Negative pressure about the lower half of the body (LBNP) has gained
a firm foothold in aerospace medicine as a functional test for evaluating the
condition of the cardiovascular system. LBNP tests permit evaluation of
dynamics of resistance to evoked redistribution of blood during antiorthostatic
[head tilted] hypodynamia and spaceflight [1-7]. Evaluation was made of the
circulatory response to LBNP. No analysis had been made of the immediate
LBNP aftereffect period, although at this time the cardiovascular system ex-
periences the burden of blood volume deposited in the lower half of the body.
The rapid equalization of pressure, which causes redistribution of blood in
the first seconds of recompression is, in essence, an independent factor.
Here too, it is possible to search for informative indicators of severity of
circulatory changes in order to assess the subject's condition.

We submit here the results of our study of the period of immediate LBNP after-
effect when applied in different modes.

Methods

These studies were conducted on 26 healthy male volunteers 21 to 35 years of
age. LBNP was created using a previously described method [8]. The immediate
aftereffect period was studied during recompression. Pressure in the gear
was equalized within 2-3 s. Cardiodynamics and hemodynamics were studied by
kinetocardiography, electrocardiography and sphygmography. From the tachy-
cardiogram, we measured duration of the cardiac cycle (C), ejection period (EP)
of the left ventricle, period of isometric contraction (IC), intrasystolic
index (ISI), myocardial contraction index (MCI), rate of build-up of intra-
ventricular pressure (RBVP). From the EKG, we determined duration of electric

systole (ES), systolic index (SI) and amplitude of R and T waves; the sphygmogram served to determine the pulse wave propagation rate (PWPR) over the great vessels.

LBNP levels used were -40 and -80 mm Hg.

Results and Discussion

LBNP is characterized by a decrease in actively circulating blood volume, increase in heart rate (HR), decrease in cardiac output, drop of pulsed and lateral systolic pressure, increase in tonus of peripheral and great vessels, alteration of phase structure of the cardiac cycle [9-10]. In the LBNP aftereffect period, there were the oppsite changes in these circulatory parameters (see Table).

The aftereffect period can be divided into three phases according to changes in main parameters of circulation: first phase, which lasts 3-4 s; second, which starts at 4-5 s and ends in the 20th s; third, which takes up the rest of the time up to the 10th min of the aftereffect period. The first and second phases are the periods of the immediate aftereffect, during which one observes the most active cardiodynamic and hemodynamic reaction to an abrupt increase in circulating blood volume. At this stage of the aftereffect period, there are diverse reactions to the drastically increased influx of blood to the heart. These reactions level off in the third phase, and initial parameters are gradually restored.

The rapid return of part of the deposited blood to the central blood stream in the first phase of the immediate aftereffect is associated with extension of EP, shortening of IC, increase in ISI and drop of MCI. The EKG showed only a relative decrease in amplitude of P wave, increase in that of the T wave and shift of electric axis of the heart to the initial position. There was no change in duration of the cardiac cycle, since apparently an increase of venous return is not sufficient for this. Nevertheless, there was some increasing in filling of the ventricles and in activation of mechanisms of heterometric regulation of the heart. This was indicated by the shifts in phase structure of the cardiac cycle.

The cardiodynamic changes in the second phase of the immediate aftereffect are probably due to reflex mechanisms that are triggered by the significant increase of venous return. This was associated with drastic extension of the cardiac cycle (up to 1.7-3 s in a number of cases) due to intensive extension of the diasystole [sic]. There was no appreciable change in duration of electric systole, while its values became shorter than nominal by 0.102±0.003 s for a given pulse rate. EP increased by 34%, IC diminished by 28% and SI decreased by 32% in relation to the level recorded with LBNP. The amplitude of P and T waves continued to gradually recover; duration of electric systole returned to background levels.

The changes in intracardiac hemodynamics are the result of acute hypervolemia, and they are inherent in the phase syndrome of blood volume load [11]. A brief blood volume load increases the initial length of myocardial fibers, and according to the principles of heterometric self-regulation of the heart this is associated with stronger cardiac contractions.

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Cardiodynamic changes in the immediate LBNP (-80 mm Hg) aftereffect period (M±m)

Parameter	Normal endurance					Diminished endurance				
	back-ground (BG)	20th min of LBNP	I	II	III	BG	20th min of LBNP	I	II	III
C, s	0,98±0,14	0,60±0,10	0,52±0,07	1,41±0,21	0,99±0,22	0,99±0,13	0,69±0,10	0,63±0,12	0,74±0,11	0,77±0,13
Q-T, s	0,375±0,08	0,320±0,09	0,310±0,08	0,320±0,07	0,370±0,08	0,380±0,06	0,310±0,08	0,300±0,08	0,320±0,09	0,375±0,07
SI, % of BG	38±1,4	54±2,4	58±2,4	26±3,2	38±1,6	38±1,8	45±2,1	47±2,0	48±2,1	48±1,8
P, % of BG	100	290	129	106	101	100	305	135	138	133
T, %	100	49	59	83	132	100	47	53	70	78
IC, s	0,038±0,009	0,053±0,008	0,04±0,009	0,038±0,006	0,035±0,009	0,044±0,01	0,058±0,01	0,031±0,01	0,033±0,01	0,049±0,008
EP, s	0,253±0,01	0,163±0,02	0,171±0,022	0,218±0,06	0,219±0,08	0,260±0,013	0,179±0,015	0,210±0,02	0,230±0,02	0,265±0,02
MCI, %	30±2,2	45±4	38±7	31±2	30±3,2	29±2,6	42±2,3	33±2,6	33±3	30±3
PWPR, cm/s	595±32	735±44	571±38	560±35	600±38	620±41	890±43	800±49	885±41	690±38

Note: I, II and III refer to phases of LBNP aftereffect.

Thus, at the immediate aftereffect stage we make a distinction between two periods of cardiodynamic changes. Those occurring in the first period are attributable to the hydromechanical factor. The rapid return of deposited blood increases filling of the ventricles, which causes relative extension of EP, shortening of IC and decline of MCI. The duration of the cardiac cycle does not change at this stage. These initial changes, in the presence of stable HR, are attributable to the mechanism of heterometric self-regulation of the heart. Subsequent changes, which develop when there is already drastic extension of the cardiac cycle, are associated with reflex influences from the sinocarotid and aortic reflexogenic zones, as well as the ostia of the venae cavae, which regulate circulation in the form of cardiocardiac and viscerocardiac reflexes. These are the changes present with normal endurance of LBNP.

The immediate aftereffect period is different when there is diminished endurance of LBNP, especially in its second phase. At this time, individuals with diminished endurance of LBNP present no reflex extension of the cardiac cycle. Duration of electric systole is close to nominal, and there is no drastic decline of the systolic index. There is more inert change in amplitude of P wave: it still exceeds its base value by 30-33%. There is also delayed restoration of T wave amplitude; EP corresponds to nominal value. There is absolute shortening of IC phase. The dynamics of changes in most parameters create the impression that there is no increase in venous return in the immediate aftereffect period. Thus, the differences between good and diminished endurance of the test are the most distinct in the second phase of the immediate aftereffect. We observed absence of reflex bradycardia at this stage, regardless of level of LBNP. This effect is specific to subjects with diminished endurance of LBNP, and it is unrelated to worsening of condition, since it was also manifested

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in the aftereffect period with use of LBNP of low levels, for example, -40 mm Hg, which is endured without subjective and objective signs of worsening of condition.

The dynamics of parameters in the aftereffect period of high values of LBNP, when this factor is associated with worsening of condition, developed against a background of changes indicative of signs of a presyncopic state. While the demonstrated bradycardia and reduced time of ejection of minute volume of blood provided for brief unloading of the heart in subjects with good endurance of this test in the second phase of the immediate aftereffect, when their condition worsens during LBNP this regulatory mechanism is not involved in the compensatory reaction. Moreover, the vascular reaction is also different at this stage of the aftereffect. A distinct impression is gained from the change in pulse wave propagation rate that there are no signs of increased venous return. A comparison of PWPR dynamics in individuals differing in individual endurance of LBNP at this phase revealed that there was absolute decline of PWPR in subjects with normal endurance and relative increase with diminished endurance. Consequently, in resistant subjects, the vessels relax in response to a marked increase in blood influx, which alleviates the unloading reflex, whereas this does not happen in subjects with diminished endurance. It can be assumed that, with diminished endurance, when LBNP is associated with development of a presyncopic state, there is no drastic increase in venous return in the immediate aftereffect period. This could be attributable to diminished tonus of arterial vessels with development of decompensation. As a result of formation of an additional volume, there is delayed return of deposited blood into the central stream and it is gradual, or else it has already occurred (with worsening of condition during LBNP test). This is suggested by the dynamics of cardiac output inherent in increased influx of blood to the heart (relative 20-30% increase) and phase structure of the cardiac cycle (longer EP, shorter IC) in the last minutes of LBNP with development of decompensation.

Analogous findings were made by American researchers [12], who demonstrated that bradycardia was absent in the aftereffect period in subjects with vasovagal symptoms that developed under the effect of sizable LBNP. The authors believe that cardiac reflexes occurring during development of a presyncopic state with exposure to LBNP blocked appearance of the usually expected bradycardia during the early aftereffect period. If this is so, it is difficult to explain the absence of reflex bradycardia in the period of immediate LBNP aftereffect, when low negative pressures were used, which had been endured quite well by the subjects. Most likely, we are dealing here with latent partial insufficiency of regulatory mechanisms of compensation of the cardiovascular system when redistribution of blood is induced.

The demonstrated distinction in subjects with diminished endurance of LBNP is specific and the effect of its manifestation is constant. Demonstration thereof does not require the use of high LBNP, and it is quite sufficient to perform the test with sparing LBNP levels that do not worsen the condition (no more than -40 mm Hg).

Subjects who presented no reflex bradycardia in the period of immediate LBNP aftereffect can be classified as individuals with inadequate reactivity of regulatory mechanisms of the cardiovascular system, and the prognosis for them may be poor for high LBNP levels.

The decline of heart rate in the recompression period is indicative of good endurance of LBNP. In our opinion, such a criterion should be taken into consideration in making expert decisions, when it is difficult to assess endurance of the test according to degree of functional strain on the cardiovascular system.

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FEASIBILITY OF SIMULATING HEMODYNAMIC EFFECTS OF WEIGHTLESSNESS WITH USE
OF POSITIVE PRESSURE

[Article by A. S. Nekhayev, V. A. Degtyarev, V. S. Bednenko and Z. A. Kirillova]

[English abstract from source] Venous and arterial circulation
was investigated by simulating cephalad blood shifts generated
by an exposure of test subjects (n = 15) to lower body positive
pressure (+25 mm Hg) and head-down tilts (at -8° and -15°). At
LBPP and tilt -15° arterial pressure increased by 5-15%. During
tilt -8° jugular vein blood filling increased by 8-94% in the
course of the first 3 hrs and then decreased reaching the base-
line (horizontal position) level. During LBPP the parameter
changed in a similar manner (increased by 2-50%). During tilt
-15° the parameter grew by 10-110% and remained elevated. The
exposures gave rise to bradycardia which was more pronounced during
-8° and LBPP. The data obtained give evidence that circulation
changes during LBPP and head-down tilts are identical. This sug-
gests that LBPP can be used to simulate the effect of cephalad
blood shifts, one of the most important effects of weightlessness
on the human body.

[Text] Diverse methodological procedures are used to simulate the effects of
weightlessness on man [1]. As we know, redistribution of blood in a cranial
direction is of substantial importance to development of functional changes
under the effect of weightlessness. Expressly this factor determines the
hemodynamics of cosmonauts in the acute period of adaptation to weightlessness
[2-4]. It is still a pressing task to search for methods of simulating the
redistribution of body fluids that would conform more to weightlessness. It is
closely linked to expansion of the possibility of forecasting cardiovascular
disorders and investigating man's adaptive reactions during spaceflights.

Methods

We conducted our studies with the participation of 15 healthy men 30-42 years
of age. In the first series of studies (5 men), redistribution of blood
to the upper half of the body was elicited by creating elevated atmospheric

pressure (+25 mm Hg) over the lower half of the body (LBPP), whereas in the second and third series (5 men in each) we did so by having them assume an antiorthostatic position (AP) with head tilted down at angles of -8 and -15°. We selected 6 h for duration of exposure to LBPP and AP. A regular vacuum device, which had been used aboard the Salyut orbital space station, was used to create LBPP, and the subject was placed into it up to the level of the iliac crests. Pressure was raised by means of a compression pump. A Mingograph-81 automatic recorder was used for hourly registration of the electrocardiogram (EKG) in the second standard lead, tachooscillogram (in the first and third series) and arteriovenous pulsogram of cervical vessels (AVP). We measured arterial pressure parameters: minimum (APd), dynamic mean (APm) lateral (AP1), end (APe) and pulsed (APp) [5]. The heart rate was determined for 30 successive R-R intervals on the EKG. Filling of jugular veins was assessed from data obtained from analysis of AVP [2].

Results and Discussion

Analysis of subjective data revealed some symptoms in common that appeared in the subjects during LBPP and AP. Right after creation of LBPP, all of them had a distinct sensation of blood rushing to the head, heaviness of the parietal region and temples. Two subjects developed headache, localized strictly in the left or right half of the forehead after 1-1.5 h. In these subjects, the sensation of blood rushing to the head and illusion of the body being dropped at a certain angle persisted for all 6 h of exposure. In the other cases, body turning illusion disappeared after 3-5 h and the position was assessed as being horizontal according to subjective sensations. All of the subjects had a flushed face, swelling of subcutaneous veins and neck, nasal speech, dry mouth and lowering of temperature of the upper extremities. In three cases, there was diminished integumental turgor on the palmar surface of the nail phalanges of the "senile finger" type. After exposure to LBPP, there was pallor of the integument of the face and hands. When they moved to erect position, the subjects experienced some instability, which became more marked when they walked with their eyes closed. The deviations from a straight line were in the range of 25 to 40 cm. In three subjects, unpleasant sensations appeared when they bent the body foreward, and they were evaluated as rapid "transfusion" of blood to the head with concomitant vertigo. These signs of discomfort persisted on the following day. In general, the findings were analogous with respect to external and subjective changes under the effect of AP, but less marked with a tilt angle of -8°. In 8 out of 10 cases, the subjects assessed their position as horizontal after 1-1.5 h of AP with both angles. In two cases, with rapid change in position to a tilt angle of -15°, the subjects developed the illusion of "twisting" of the body in a spiral, which lasted about 10-15 h.

Analysis of the data obtained during AVP recording revealed that maximum deviations from base values (horizontal position) in amplitude of presystolic (Aa) and diastolic (Ad) AVP waves, which were indirectly indicative of the relative level of filling of jugular veins during right atrial systole and diastole, were noted with AP at an angle of -15°. The increase in Aa and Ad amplitudes was individual in nature, ranging from 10 to 110% at different stages of exposure (Figure 1). The dynamics of mean values of these parameters with a -8° tilt in AP and LBPP were similar. The increase in Aa and Ad waves in the first 3 h of AP constituted 8-94% in 4 subjects, whereas one subject presented a tendency toward 4-29% decline, as compared to base values.

The mechanism of this effect is not yet quite clear. With exposure to LBPP, Aa increased by 2-50% in all subjects during the first 3 h, after which it diminished and came close to base values. In general, the dynamics of Ad were in the same direction as Aa. We were impressed by the considerable scatter of individual Aa and Ad values in AP. It was considerably less marked with LBPP. This can apparently be attributed to the fact that the method we used was unrelated to the effect of the gravity factor, which is difficult to calibrate [norm], and it is based on use of a uniform effect of elevated atmospheric pressure over about half the body area.

Figure 1.

Dynamics of mean values of amplitudes of presystolic (ΔAa), diastolic (ΔAd) AVP waves, heart rate (ΔHR) during exposure to LBPP (1), AP at -8° (2) and AP at -15° (3) angles.

Figure 2.

Dynamics of mean values of arterial pressure parameters: mean (ΔAPm), lateral (ΔAPl), end (ΔAPe), minimum (ΔAPd) and pulsed (ΔAPp) during exposure to LBPP (1) and AP -15° (2)

In both figures: all parameters are given in relation to base values; t time of exposure.

The results also indicate that filling of jugular veins remains increased throughout the exposure period in the case of AP at an angle of -15° (according to mean values of Aa and Ad), whereas with AP at an angle of -8° and LBPP compensation of hypervolemia in the great vessels of the system of the superior vena cava was demonstrable, starting in the 4th h. In our opinion, this circumstance is of positive significance, from the standpoint of possibility of tracking the process of adaptation of the cardiovascular system to redistribution of blood under conditions of short-term simulation thereof. With AP at an angle of -15°, the hydrostatic components elicited by the effect of gravity forces, which occur in the vascular bed, become more significant. As a result, the

dynamic conditions of venous circulation in the system of the superior vena cava change, apparently to a significant extent, and the compensatory reactions to reduce hypervolemia are inadequate.

Studies of systemic hemodynamic (Figure 2) revealed identical changes in parameters of arterial pressure with AP of -15° and LBPP. With both factors, most of the AP parameters exceeded base values by an average of 5-15% (with the exception of APe in the first 3 h and APp in the last 4 h of exposure to LBPP). In all series of tests, we observed a tendency toward bradycardia. Maximum deviations were noted with AP at an angle of -8° and LBPP. HR diminished by an average of 5-13%, there being considerable individual scatter (see Figure 1).

The results of studying venous and arterial hemodynamics with use of AP and LBPP, as well as subjective data, were similar to those observed in most cosmonauts during flights [2, 3, 5].

Thus, both AP and LBPP can be used as means of simulating reactions of the cardiovascular system to redistribution of blood in a cephalad direction. At the same time, in our opinion LBPP is preferable to AP, since it does not elicit changes in direction of effect of the hydrostatic factor in the cardiovascular system and reorientation of reflexes caused by afferent impulsation from systems, organs and tissues exposed to opposite strain and deformity with AP.

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EVALUATION OF MAN'S PHYSICAL CONDITIONING ACCORDING TO ENERGETICALLY OPTIMUM WALKING SPEED

[Article by V. V. Verigo and V. A. Tkachenko]

[English abstract from source] This paper describes methods for evaluating energy expenditures associated with terrain cure walking under the assumption of additivity of expenditures involved in walking along flat and rugged terrain. It has been shown that people of different physical fitness have different values of energetically optimal walking speed. The concept of the energetically optimal speed allows quantitative estimations of movement associated energy expenditures, taking into accound individual exercise tolerance.

[Text] Experience with the use of resort factors in mountains of moderate altitude to facilitate and accelerate the process of rehabilitation of individuals exposed for a long time to extreme conditions demonstrated the efficacy and desirability of using a set of therapeutic and rehabilitation measures. In this set, the method of graded walking (cross-country), which is used to rehabilitate individuals with chronic, "domestic" hypokinesia and disorders that developed on this basis, holds a prominent place. Cross-country walking is instrumental, in particular, in mobilizing the compensatory capabilities of the body, which leads to increased tolerance of physical loads.

Long-term experience with physical loads for testing and conditioning purposes revealed that it is expedient to divide all patients into four groups [2, 3]. Such separation should be based on degree of adaptation to exercise, which is determined from the results of physiological tests and EKG findings. Consideration is also given to severity of deviations in activity of the cardiovascular system. The level of energy expended when covering the route of a cross-country walk ["terrain cure"] can also serve as a criterion of endurance of such walks, since it was proven that the same group of subjects expends less energy on the walk after receiving a course of therapeutic measures. Thus, a group of patients, which consisted of 66 men 50-59 years of age who had a risk factor for ischemic heart disease (IHD) expended 276 kcal (estimated according to change in HR [heart rate]) on a 4400 m hike with 61-m gradient

in altitude before treatment. After therapy, this parameter constituted 256 kcal. They walked at a rate of about 4.8 km/h. Qualitatively similar data were obtained for other routes. It is interesting to work out a method that would allow us to estimate the energy expenditure for the route, on the basis of its length and topography, as well as conditioning or condition of the patient, without resorting to the complicated procedures of direct measurement of expended energy.

To date, there are several works that deal with questions of biomechanics of walking in the aspect of energy expended with different modes thereof. A long list of references is provided in [4, 5]. Most researchers assume that expended energy is proportional to the square of average walking speed. The function proposed by Ralston determines specific energy expenditure (E_s, in calories/kg body weight) for traveling route S, in meters, at speed [V] (in m/min) in the following form:

$$E_s = \frac{S}{V}(a + bV^2),\qquad(1)$$

where $a = 29$ and $b = 0.0053$.

This estimate is referable to walking in a flat area. In addition to the above expenditure of energy, one must take into consideration energy expended (E_h) to counteract gravity, when the body's center of mass shifts during an uphill walk:

$$E_h = mg\Delta h,\qquad(2)$$

where m is mass, g is acceleration of earth's gravity and Δh is the shift in the gravity field.

When the route is not very steep, which is usually provided in therapeutic terrain cures, overall expenditure of energy can be estimated as the sum of E_s and E_h:

$$E = mE_s + E_h.\qquad(3)$$

Let us analyze E_s as a function of speed. With $V \to 0$, there would be infinite extension of time spent on traveling the route, and energy expenditure will also increase, in spite of the negligible speed. The increase in E_s with increase in V at rather high speeds is obvious. Consequently, there is an energetically optimum walking speed (EOS). This fact has also been confirmed in experimental studies. According to different data, EOS is slightly over 4 km/h. We shall determine its dependence on parameters a and b in equation (1) on the condition of minimum energy according to speed $dE_s/dV = 0$:

$$\frac{dE_s}{dV} = \frac{S}{V^2}(bV^2 - a).\qquad(4)$$

To satisfy condition $dE_s/dV = 0$, it is necessary for the following equation to be valid:

$$V = \sqrt{\frac{a}{b}}.$$
(5)

The parameters cited by Ralston for equation (1) correspond to an optimum speed of 74 m/min or 4.45 km/h. For other values of EOS, parameter b would apparently have a different value.

It can be assumed that the optimum walking speed will differ for groups that differ drastically in level of conditioning. For those undergoing sanatorium and resort therapy, it should apparently be lower than for physically healthy groups of subjects. Let us illustrate this with an example. On one of the routes used by individuals undergoing treatment at the Krasnyye Kamni [Red Stones] Sanatorium, energy expended was 255 kcal when walking at the rate of 4.8 km/h at the start of therapy and 214 kcal at the end (distance 3000 m, elevation gradient 151 m). Energy expenditure calculated with equation (3) for the optimum speed of 4.45 km/h and body weight of 75 kg, was found to be 203 kcal, i.e., it was close to the expenditure after the course of therapy. However, if we assume that at the start of the stay at the sanatorium EOS for the above-mentioned group constituted only 3.6 km/h (which conformed to the bottom limit of rapid walking when climing a hill with 5-10° slope, according to indications in [2]), energy expended by an individual weighing 75 kg would be estimated at 252 kcal. The assumption that optimum speed of movement that is close to 4.2 km/h at the start of treatment would increase to 4.8 km/h after the course of therapy was also confirmed for the above-mentioned 4400-m distance and altitude gradient of 61 m. The estimate showed that energy expenditure was 287 and 269 kcal, which is quite close to the directly estimated figures of 276 and 260 kcal. Thus, the assumption that there are different optimum speeds of walking for groups of individuals differing in physical conditioning and fitness appears quite probable.

There are several aspects of practical use of this fact and use of formula (3) to assess expended energy. EOS, after being estimated according to energy expended for the walking distance, could serve as a criterion to arrange subjects in groups differing in conditioning. For this reason, the terrain cure hike can be viewed as a distinctive load test, which has a "milder" effect than, for example, the test using a bicycle ergometer. On the other hand, estimation of EOS for different groups makes it possible to calculate energy expenditure for different distances and speeds over them, as well as to plan motor conditioning regimens. The feasibility of objective evaluation of mean energy expended over the distance by means of calculation eliminates the need to involve a physician to accompany patients and measure their heart rate. The telemetry method of monitoring the heart rate is not always adequate because of the irregular topography of a locality and great distance of a number of points on the route.

As we have already indicated, what is relevant in the proposed method is the assumption [suggestion?] of independent expenditure of energy for walking and climbing, as well as independent expenditures of energy in different

parts of the terrain. Both these conditions are valid for small angles of slope and average pace of walking, i.e., for the routes generally used in rehabilitation practice. Extension of the method to passage over individual segments of the route with a submaximum load (slope of terrain, walking speed) perhaps will require some generalization. One must take into consideration the fact that meteorological conditions, clothing and other factors also affect the amount of energy expended, and they must be standardized in a specific way for adequate use of the method.

At the present time, the proposed method of quantitative estimation of energy is being tested on a group of people undergoing sanatorium and resort therapy because of ischemic heart disease and other diseases. However, in the future we intend to use it for scheduled conditioning of individuals undergoing rehabilitation after working under extreme conditions, in particular, after spaceflights. The results of medical examination of crew members are indicative of signs of asthenization and vegetovascular dysfunction [6]. For this reason, there is some resemblance of the set of rehabilitation and therapeutic measures used for them and the one used for subjects undergoing rehabilitation from the sequelae of chronic hypokinesia on the ground. It is considered an important task to work out the optimum motor regimens of therapeutic cross-country hikes to rehabilitate crew members, with due consideration of the specifics of this task.

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BIOCHEMICAL CHANGES IN CANINE BLOOD PLASMA UNDER EFFECT OF REPEATED EXPOSURE TO ACCELERATIONS

[Article by R. A. Vartbaronov, G. D. Glod, Yu. P. Lanovenko and N. N. Uglova]

[English abstract from source] For 3 months experimental dogs were exposed to +Gz acceleration applied 3 times a day for 3 days a week. The initial acceleration value was 8-9 G, then the parameter varied, depending on the tolerance limit which was evaluated with respect to heart rate disorders. Biochemical measurements showed the largest changes (decrease in total protein, increase in sugar, bilirubin, cholesterol, alkaline phosphatase and transaminases) after the first day of the repeated exposure to +Gz. Following 1-3 months of the exposure, the changes decreased significantly; however, the K^+ concentration continued to decline and that of alkaline phosphatase continued to increase. The results obtained indicate the development of adaptation to repeated +Gz exposures which differs from that to short-term exposures.

[Text] The problem of regular and repeated exposure to prolonged "head-pelvis" (+Gz) accelerations, as well as the adaptive and cumulative effects that are produced, has thus far not been sufficiently investigated, in spite of the importance of these questions to aviation medicine [1, 2]. There are only a few studies conducted on rats to investigate the regular effect of single exposure to +Gz accelerations [1, 3]. A combined investigation, which we conducted in this direction, revealed that it is imperative to submit this problem to comprehensive study. We submit here the results of a study of severity and direction of changes in some biochemical parameters of canine blood plasma under the systematic, repeated effect of maximum tolerable +Gz accelerations.

Methods

Experiments were conducted on 3 adult male dogs weighing 9-11 kg. The dogs, which were immobilized in a special container [4], were exposed to +Gz accelerations on a centrifuge with a 4.25 m arm. In order to minimize traumatization, we used restraining gear [suits] and liners made of thick

porolon [foam plastic]. All of the dogs underwent a stage of habituation to restraint in the container, then for 1 week they were exposed to accelerations once a day every other day, with 30-s plateau and gradual build-up thereof from 2 to 10 units: to 4 on the 1st day, to 6 on the 2d and to 8-10 on the 3d.

After preparing the animals in this manner, we commenced the main experiment.

In this experiment, regular exposure to accelerations was effected 3 times a week for 3 months. The Figure illustrates the schedule of repeated exposure per day. On the first day of the main experiment, the initial accelerations constituted 8-9 units; on subsequent days, in each successive cycle, the maximum acceleration was either reduced by 0.5 units upon reaching the limit of endurance, as assessed by marked changes in cardiac rhythm on the EKG, or increased by the same amount in the absence of signs of reaching this limit.
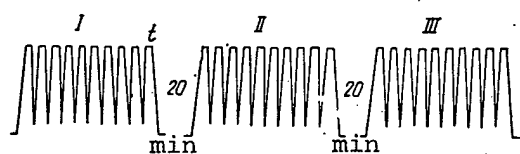
Schedule of modes of repeated exposure to cycles (I-III, 7.5 min each) of maximum tolerable +Gz in the course of 1 day.
Plateaus/cycle 10; minimum acceleration 2 units, maximum 8-12, gradient of change 1 unit/s; duration of plateau 30 s

We took blood from the dogs by a well-known method [5] on the day after exposure. Plasma was examined on an SMA-12/60 Technicon Co. automatic biochemical analyzer for 12 parameters.

Biochemical tests were made 2-3 times before the experiment, after completion of the weekly cycle of single exposures to accelerations, after the 1st day of repeated exposure to +Gz, 1, 2 and 3 months after the start of the chronic experiment. This approach enabled us to single out primarily the effects of chronic exposure.

Results and Discussion

Plasma showed a reliable increased (11%) in total protein, alkaline phosphatase (AP, by 48%) and negligible increase (3-5%) in Na^+ and Cl^- ions after termination of the cycle of conditioning rotation related to single exposure to accelerations (first stage).

After the 1st day of repeated exposure to +Gz (stage II), we observed more marked changes in many biochemical parameters: reliable decrease in plasma total protein, increase in sugar, cholesterol, bilirubin, increase in concentration of AP, AST [aspartate aminotransferase] and ALT [alanine aminotransferase] (see Table).

Subsequently, after 1-3 months of regular exposure to +Gz (stage III), most of the above changes (with the exception of AP and K^+ ions) leveled off significantly, and this could be indicative of development of the systemic adaptation syndrome [6] with signs of long-term adaptation [7], considering the findings at the first and second stages.

A finding specific to regular exposure to +Gz accelerations was the decrease in plasma K^+ ions (by 10%) and corresponding increase of the sodium-potassium ratio (Na^+/K^+). According to our data and information in the literature [8, 9], such a reaction is not typical of an acute effect, and

probably could affect the stage of incipient depletion of adaptive mechanisms, along with decrease in total protein content.

Results of biochemical blood tests on dogs with exposure to +Gz

Parameter	Background	Stage of experiment		
		I	II	III
Total protein, g%	6,8±0,13	7,55±0,22*	6,00±0,16**	5,85±0,23**
Urea nitrogen, mg%	18,9±2,7	16,0±2,1	14,0±0,6	16,0±2,3
Creatinine, mg%	1,45±0,11	1,25±0,09	1,35±0,03	1,29±0,07
Sugar, mg%	91±2,7	93±2,0	107±3,5**	97±1,5
Cholesterol, mg%	116±7,1	129±7,7	165±20,5*	127±6,2
Bilirubin, mg%	0,125±0,017	0,10±0,025	0,20±0,03*	0,19±0,05
Cl⁻ ions, meq/l	113±0,4	116±0,3***	114±0,6	116±1,7
Na⁺ ions, meq/l	151±1,5	159±1,1**	149±1,1	150±0,8
K⁺ ions, meq/l	4,26±0,065	4,35±0,13	4,27±0,13	3,84±0,08***
Sodium-potassium ratio (Na+K+), relative units	35,5±0,5	36,6±1,0	34,9±1,3	39,1±0,7***
AST, arbitrary units	34,8±2,0	39,5±4,8	130±38,0*	37,5±3,4
ALT, " "	68±8,0	101±28	200±17,5***	149±26,8*
AP, " "	27±1,6	40±3,2**	65±4,8***	78±4,6***
Number of readings	8	6	4	9

Note: Reliability of differences is given according to Student's criterion in relation to baseline background.

*P<0.05   **P<0.01   ***P<0.001

Plasma concentration of AP, which increased progressively and significantly (by 50-190%) at all stages of the chronic experiment was the most sensitive biochemical parameter with reference to the factors used. The rise of this parameter, as well as in concentration of aminotransferases, could be indicative of impaired permeability of cell membranes due to the effect of accelerations, according to the data of some authors [7, 10].

Our findings are indicative of complex and dissimilar effects of canine adaptation to regularly repeated exposure to +Gz accelerations, which differed in nature of biochemical reactions from those of short-term exposure, and this is indicative of the desirability of pursuing further studies.

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REPRODUCTIVE FUNCTION IN MALE RATS AFTER FLIGHT ABOARD COSMOS-1129 BIOSATELLITE

[Article by L. V. Serova, L. A. Denisova, Z. I. Apanasenko, M. A. Kuznetsova, Ye. S. Meyzerov and N. A. Chel'naya]

[English abstract from source] Male rats that were flown for 18.5 days on Cosmos-1129 were mated postflight with intact females. The mating 5 days postflight when the ejaculate consisted of spermatozoids that were exposed to zero-g effects in the mature stage yielded the litter which lagged behind the controls with respect to the growth and development during the first postnatal month. The mating 2.5-3 months postflight when the ejaculate consisted of spermatozoids that were exposed to zero-g effects at the stem cell stage yielded the litter which did not differ from the control.

[Text] Previous histological studies of testes of animals flown in biosatellites failed to demonstrate appreciable changes in spermatogenic tissue or disturbances of the process of spermatogenesis [1, 2]. In the experiment aboard Cosmos-605 biosatellite, male rats from the flight group were mated with intact females 2-2.5 months after returning to earth. The offspring did not differ from control offspring in total number of neonates, birth weight, dynamics of weight gain in the 1st postnatal month, weight of organs, blood findings and resistance to hypoxia [3]. However, in this case, the interval between the end of the flight and mating was longer, considerably longer than the flight itself, and no special embryological tests had been used on the animals.

We submit here the data obtained in Cosmos-1129 concerning the offspring of male rats exposed to weightlessness and then mated with intact females 5 days and 2.5-3 months after returning to earth. In the former case, the ejaculate consisted of sperm that was exposed to weightlessness in a mature state, and in the latter it was exposed at the stem cell stage of spermatogenesis, i.e., spermatogonia.

Methods

We used mature (5 months old at the start of the flight) Wistar SPF rats from the vivarium of the Institute of Experimental Endocrinology of the Slovak Academy of Sciences (Bratislava, CSSR).

The animals were kept in a unit consisting of two communicating compartments, 14×20×42 and 14×20×24 cm in size, during the spaceflight, which lasted 18.5 days. Ambient temperature in the area where the animals were located was in the range of 23.5-25.5°C, and relative humidity was 55-65%; pO_2 was 135-212 mm Hg and pCO_2 up to 6 mm Hg. Concurrently with the flight, we conducted a ground-based synchronous control experiment in a biosatellite mockup, in which upkeep conditions and physiologically significant factors related to lift-off and landing of the craft were simulated (vibration, accelerations, noise, impact accelerations). The animals of the vivarium control were kept at a temperature of 22-25°C in 20×32×54 cm cages. All three groups of animals were given water and special feed paste [4]--55 g/day/rat. After the flight, the animals were gradually switched to mixed feed, adding it to the special feed.

After they returned to earth, the flight group of male rats were mated with intact (kept in the vivarium) females at 2 different times: on the 5th post-flight day and 2.5-3 months after the flight. Males from the synchronous and vivarium groups were mated at the same times with intact females.

We used 6 male rats: 2 in the group flown aboard the biosatellite, 2 in the synchronous experiment and 2 in the vivarium control. At each mating time, 3-5 females were put with each male. In the first series of experiments (mating 5 days after the flight), we examined 15 litters of 10-13 rats each; in the second series (mating after 2.5-3 months) we examined 28 litters.

Some of the females were dissected on the 21st day of the gestation period; determination was made of implantation and resorption percentages, total embryonic deaths, number of live fetuses, weight and dimensions of fetuses and placenta.

In the other cases, we observed the newborn rats for the first postnatal month, with evaluation of growth rate, time when their eyes opened, ears were no longer adherent and appearance of pelage. We used the Wilson method as modified by A. P. Dyban et al. [5] to examine soft tissues and viscera of fetuses and newborn rats.

When the rats reached the age of 30 days, they were submitted to a 2-h immobilization stress test. We evaluated the reaction to the test according to the cytogram of peripheral blood and behavior in a Lachman maze. The digital data were processed with use of Student's t criterion.

Results and Discussion

We found an increased number of rats per litter (average of 13, versus 10 in the vivarium control) from females mated with flight group males 5 days after their return to earth; however, a similar increase was also observed in the offspring of males in the synchronous experiment. Average birth weight was the same in all three groups (6.1-6.5 g).

The offspring of flight and synchronous groups showed an increase in number of females (122-124 per 100 males, versus 91 in the vivarium control), which could be due to the various stressor situations that were present in both instances.

Table 1. Relative organ weight in offspring of flight and synchronous group males mated with intact females 5 days after flight

Mated animals ♂	Mated animals ♀	Rat age, days	Rats per litter	Body weight (g)	thymus	spleen	liver	kidneys	myocardium
					Relative organ weight, % of body weight				
S	V	1,5	12—13	7,88±0,27	0,146±0,006	0,361±0,005	3,580±0,082	0,819±0,026	0,482±0,009
F	V	1,5	12	7,77±0,13	0,133±0,011	0,294±0,023	4,030±0,096	0,958±0,032	0,493±0,007
						$P<0,01$	$P<0,01$	$P<0,01$	
S	V	6	10	13,7±0,21	0,264±0,021	0,572±0,015	2,921±0,057	1,235±0,041	0,587±0,021
F	V	6	14	12,1±0,2	0,202±0,011	0,475±0,014	2,575±0,108	1,263±0,034	0,503±0,017
					$P<0,01$	$P<0,001$	$P<0,01$		$P<0,01$

Key for Tables 1, 2, 3   F) flight group   S) synchronous experiment   V) intact vivarium control

Table 2. Reaction to immobilization-stress test in 30-day offspring of flight, vivarium and synchronous groups of males mated with intact females 5 days after flight

Mated animals ♂	Mated animals ♀	Number of offspring	leukocytes	neutrophil	lymphocytes	lymphoc./neutrophil	leukocytes	neutrophil	lymphocytes	lymphoc./neutroph.
			Peripheral blood cytogram, thousands per mm^3							
			before test				after test			
V	V	12	10,4±0,7	2,67±0,37	7,53±0,46	3,37±0,44	12,8±1,0	7,30±0,84	5,12±0,38	0,79±0,10
S	V	11	9,7±0,7	2,22±0,21	7,03±0,54	3,41±0,38	12,7±1,0	7,31±0,56	5,26±0,53	0,72±0,06
F	V	12	8,1±0,3	1,84±0,13	5,92±0,25	3,33±0,25	9,7±0,5	4,89±0,41	4,37±0,21	0,89±0,10
			$P_B<0,01$	$P_B<0,05$	$P_B<0,01$		$P_{BC}<0,02$	$P_B<0,02$ $P_C<0,01$		

Table 3. Parameters of embryonic development of fetuses of intact females mated with flight, synchronous and vivarium groups of males 2.5-3 months after flight

Mated animals ♂	Mated animals ♀	Number of rats ♂	Number of rats ♀	Quantity of corp. lutea	Quant. implantations	Quant. resorptions	Quant. fetuses	% implantations	% resorptions	% dead fetus	Overall embryo mortality	Fetus mass, g	Fetus size, cm	Placenta mass, g	Placenta size, cm
F	V	2	11	15,0±0,71	9,9±1,7	1,6±0,7	8,5±1,4	63,6±9,1	13,6±4,9	0	45,3±7,9	3,1±0,1	3,3±0,2	0,61±0,1	1,39±0,5
S	V	2	9	15,2±0,8	11,8±1,3	0,3±0,2	11,4±1,2	79,0±8,7	2,0±1,4	1,4	23,5±8,7	3,5±0,04	3,4±0,04	0,49±0,03	1,33±0,04
V	V	2	8	15,0±0,9	10,4±1,6	2,0±0,5	8,4±1,8	67,5±9,1	22,3±9,1	0	42,5±10,5	3,4±0,1	3,3±0,05	0,54±0,04	1,35±0,5
												$P_B<0,02$ $P_C<0,01$			

Examination of soft tissues and viscera of neonates by the Wilson method in the modification of A. P. Dyban [5] revealed an increase in quantity of baby rats with deviations from normal to 37% among those born to flight males, versus 11% increase in the synchronous experiment and 19% in the vivarium contorl All of the deviations among offspring of control groups consisted of edema and hemorrhages, whereas the offspring of males that had flown in space also presented abnormalities of internal organs: hydrocephalus, ectopic kidneys, enlargement of the bladder. There were no deaths of offspring in the first postnatal month in any of the groups.

We observed reliable retardation of growth of offspring from flight group males, as compared to the synchronous control: on the 6th day, weight of experimental and control offspring constituted 10 and 13 g, respectively, on the 8th day 15 and 18 g, on the 12th day 22 and 26 g, on the 18th day 26 and 32 g. In all instances, we compared litters consisting of the same number of rats.

Examination 1.5 days after birth revealed a reliable decrease in absolute and relative weight of the spleen, increase in weight of liver and kidneys in offspring of flight group males, as compared to the control; thymus and myocardial mass did not change. On the 6th postnatal day, there was reliable decrease in relative mass of the spleen, liver and myocardium (Table 1).

Studies of some parameters of physical development in the first postnatal month revealed retardation in rats born to flight group males bred with intact females, as compared to the offspring in the synchronous experiments. This was manifested by later "unsticking" of the ears, eye opening, appearance of pelage and other changes. Thus, in the control group the number of rats with detached ears constituted 90% already on the 3d day and 100% on the 4th day, whereas this applied to only 50% of the baby rats referable to offspring of flight males on the 3d day and the parameter reached 100% only on the 7th day.

In the control group, most baby rats (70%) had open eyes on the 13th day, as opposed to the offspring of males exposed to weightlessness, none of which had opened its eyes on the 13th day, and even on the 14th day only 27% had their eyes open.

The first signs of pelage appeared on the 5th day in offspring of the control group, and 2 days later in rats born to flight group males. The difference in degree of development of pelage disappeared only by the 13th day.

There were 20-30% more immobile rats among the offspring of flight males up to the 9th day, as compared to offspring of control animals.

When the rats reached the age of 30 days, they were submitted once to 2-h immobilization stress. The reaction to this test was evaluated according to the peripheral blood cytogram and behavior in a Lachman maze. Examination of offspring of flight group males before the test revealed some decline (within the range of the physiological norm) in total leukocyte count referable to uniform decrease in lymphocytes and neutrophils (Table 2), as compared to the control. The direction and severity of changes in response to the stress test were the same in offspring of flight group males as offspring of control animals: in blood samples taken from experimental animals at the end of immobilization, total leukocyte count constituted 120% of the initial level (versus 123% in the

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control), netrophils 266% (273% in the control) and lymphocytes 74% (68% in the control). At the same time, in assessing behavior in the Lachman maze after the stress test, there was a considerable increase (up to 50%) in quantity of young rats that did not solve the problem among the offspring of experimental animals (9% for offspring of the synchronous control), which is apparently indicative of worsening of endurance of stress test by offspring of male rats submitted to weightlessness.

Flight, synchronous experiment and vivarium groups of males were again mated with intact females 2.5-3 months after returning to earth.

In this series of experiments, we evaluated the condition of the fetuses on the 21st day of the gestation period. Females mated with males from the flight group did not differ from those mated with males from the vivarium and synchronous controls with regard to percentage of implantations and resorptions, overall embryo mortality, quantity of live fetuses, weight and size of fetuses and placenta (Table 3).

Examination of soft tissues and viscera of fetuses also failed to demonstrate differences between offspring from flight and control groups of males. Total quantity of deviations from normal constituted 18.3% among offspring of the flight group, 22.9% for the synchronous experiment and 19.4% for the vivarium control. In essence, the deviations consisted of hemorrhages; visceral abnormalities constituted 2.8% in offspring of flight group males, 4.2% in offspring of males in the synchronous experiment, there being none among the offspring of the vivarium control.

In a previous experiment aboard Cosmos-605 biosatellite, we mated flight group males with intact females at virtually the same time (2-2.5 months after the flight) and followed up on offspring development for the first postnatal month. No differences were demonstrated between offspring of experimental and control animals with regard to dynamics of changes in weight of body, organs, blood findings and resistance to hypoxia [3].

Thus, the offspring obtained from mating flight group males with intact females 2.5-3 months after returning to earth, when the ejaculate consisted of sperm that was exposed to flight factors at the stem cell stage of spermatogenesis, did not differ from the offspring of the control group in any of the parameters we tested. However, when the rats were mated 5 days after the flight, when male ejaculate consisted of spermatozoa exposed to weightlessness at the mature stage, the offspring showed retardation from the offspring of control animals, with regard to dynamics of growth and development in the first postnatal month. Even at the age of 30 days, these animals endured worse the immobilization-stress test than offspring of control rats.

Apparently, the above-described changes are not caused by changes in the genetic system of spermatozoa, but by temporary decrease in quantity thereof and worsening of functional state. It is known that a change in these parameters can affect the course of fetal and neonate development [6, 7].

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EFFECT OF STRESS ON NUCLEIC ACID METABOLISM IN RAT SPLEEN AND LIVER FOLLOWING FLIGHT ABOARD COSMOS-1129 BIOSATELLITE

[Article by G. S. Komolova, Ye. N. Troitskaya, I. A. Yegorov and R. A. Tigranyan]

[English abstract from source] Changes in nucleic acid metabolism of the spleen and liver of rats flown for 18.5 days on Cosmos-1129 were investigated. Postflight changes in the liver RNA synthesis after an additional stress effect (immobilization) in the flown rats were expressed to a lesser degree than in the controls. The DNA synthesis remained essentially at the preflight level. The tissue content of nucleic acids suggests that postflight the dystrophic changes induced by the additional stress effect increased. It is very likely that an exposure to space flight effects contributes to the depletion of compensatory mechanisms maintaining the normal level of metabolic processes.

[Text] Adaptation to spaceflight conditions occurs by means of functional and morphological adaptive changes implemented by biochemical mechanisms. According to current conceptions, the molecular mechanisms of animal adaptation to extreme factors are based on changes in the nucleic acid system [1].

The adaptive capabilities of the body are limited, and with excessively long or strong extreme factors its protective reserve is depleted, and this is also manifested in the system of nucleic acids [2].

In the "Stress" experiment, which was conducted aboard Cosmos-1129 biosatellite, the objective was to investigate the effect of a long-term spaceflight on the adaptive reserve of different systems of the body. To do this, studies were made of their reactivity to an additional stress factor (immobilization). We submit here data on the state of nucleic acid metabolism in the rat liver and spleen under the effect of the above factor.

Methods

Experiments were conducted on male Wistar rats weighing about 300 g. They were flown in space for 18.5 days aboard Cosmos-1129 biosatellite. Animals kept in the vivarium, on the same diet as experimental rats, served as a control.

We simulated the dynamic spaceflight factors (with the exception of weightlessness) in a synchronous variant of the experiment, and animals were kept on the same life-support systems as those in flight. The animals were divided into 3 groups, according to time at which they were decapitated: the first group (7 rats) consisted of animals decapitated 6 h after landing, the second (6 rats) group were decapitated after 6 days and the third (7 rats) also after 6 days, but these animals were submitted to immobilization stress for 2.5 h at the same time of day on 0-6 days. In the control variants (vivarium and synchronous), the experimental protocol was the same as in the flight variant.

Spectrophotometry was used to assay concentration of nucleic acids in tissue homogenates and nuclei [4]. The specimens were successively treated under refrigeration with 0.5 N perchloric acid to remove acid-soluble products, mixture of ethanol and ethyl ether (1:1 by volume) and finally with ether to remove lipids and for dehydration. Dry specimens were hydrolyzed in alkali for 1 h at 37°C. After centrifugation, the supernatant was neutralized in perchloric acid, and its RNA content was assayed. The precipitate was submitted to acid hydrolysis for 20 min in a boiling water bath. DNA was demonstrated in hydrolysates after centrifugation. Nuclei were isolated from the liver by the method of Chauveau [5]. We examined RNA synthesis in isolated nuclei by a previously described method [6]. Intensity of DNA biosynthesis in isolated nuclei was evaluated according to incorporation of labeled thymidine in 15 min at 37°C, in a medium consisting of the following: 47 mM tris-HCl, pH 8.0; 5 mM $MgCl_2$, 15 mM KCl, 7.7 mM mercaptoethanol, 1.6 mM ATP, 0.08 mM of each deoxytriphosphate (GATP, GGTP, GCTP), 0.02 mM ^{3}H-TTP (specific activity after dilution in unlabeled TTP [thymidine triphosphate] 280 mCi/mmole). The reaction was stopped with cold perchloric acid. The precipitate was eluated many times and hydrolyzed for 20 min at 90°C in 0.5 N $HClO_4$. The hydrolysates were analyzed for radioactivity, using a toluene scintillation mixture with Triton X-100. Radioactivity of the specimens was measured with an SL-4000 liquid scintillation counter (made in France).

Results and Discussion

It is known that the weight of the animal spleen drops in spaceflight or with prolonged immobilization on the ground [7, 8], and a diminished RNA content is found in the remaining cells [9], which is apparently due to impairment of transcription processes [10].

In the experiment conducted aboard Cosmos-1129 biosatellite, the weight of the spleen dropped reliably (by 29%) on 0 day, as compared to the vivarium control. According to data in Table 1, in the postflight period there was an increase in DNA concentration in remaining tissue. As compared to 0 day, 6 days after the flight this increase constituted 43%. At the same time, RNA level remained in the normal range. In the synchronous experiment, there was no change in DNA concentration, but there was a tendency toward decrease in RNA (differences are statistically unreliable). Additional stress (immobilization) elicited a decrease in spleen mass in all experimental variants, but to a somewhat greater extent in the flight experiment (29%, versus 14 and 20% in the vivarium and synchronous variants, respectively). The concentration of DNA in spleen tissue increased and that of RNA decreased. The effect was the most marked in the flight variant of the experiment. DNA concentration in the spleen of flight animals was 3 times greater than in the corresponding control; however,

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only by 21 and 30% in the rats of the vivarium control and synchronous experiment. The decrease in RNA concentration caused by immobilization constituted 55% in the flight variant, versus 36 and 21% in the vivarium control and synchronous experiment. Analogous, but less marked, changes were noted in the liver (see Table 1).

Table 1. Nucleic acid content of the rat spleen and liver (M±m)

Variant	Group	Spleen		Liver	
		DNA, μg/ mg dry tissue	RNA μg/ kg dry tissue	DNA, μg/ mg dry tissue	RNA, μg/ mℓ dry tissue
Vivarium control	1	45,8±2,3	95,8±1,3	17,7±1,1	59±1,3
	2	48,3±2,8	87,3±3,7	17,6±1,2	55,6±4,3
		—	— $P_1>0,05$	—	—
	3	55,6±1,1	75,8±4,6 $P_1<0,05$	20,5±0,6 $P_1<0,05$ $P_2<0,05$	59,6±4,4
Synchronous experiment	1	46,4±1,9	91,4±6,1	15,1±0,6	49±0,7
	2	50,1±2,8	74,6±9,5	18,4±0,7 $P_1<0,01$	56,7±1,2 $P_1<0,001$
	3	64,5±1,8 $P_1<0,001$ $P_2<0,01$	58,7±1,6 $P_1<0,001$	2,02±0,6 $P_1<0,001$ $P_2<0,05$	62±0,8 $P_1<0,001$ $P_2<0,01$
Flight	1	29,9±4,2	89,8±3,6	14,0±1,2	48,8±0,9
	2	42,9±5,1 $P_1<0,05$	88,3±3,9	15,7±1,3	53,6±0,7 $P_1<0,001$
	3	98,4±5,4 $P_1<0,001$ $P_2<0,001$	40,0±4,3 $P_1<0,001$ $P_2<0,001$	20,1±1,1 $P_1<0,01$ $P_2<0,05$	61,5±0,9 $P_1<0,001$ $P_2<0,01$

Note: Here and in Table 2, P_1 and P_2 were calculated in comparison to results for the first and second groups, respectively.

Slight increase in nucleic acid content of the liver was noted in the flight and synchronous variants after 6 days (as compared to 6 h after the experiments). However, no statistically significant differences were demonstrated in the results of ground-based and flight experiments. Immobilization caused an increase in DNA concentration of the liver, by 42% in animals flown in space, versus 15% in the vivarium control. In the synchronous experiment, the effect constituted 34%. Immobilization had virtually no effect on RNA level in the liver of animals of the vivarium control, whereas its concentration increased by 27 and 26%, respectively, in animals of the synchronous and flight experiments, respectively. Immobilization led to statistically reliable change in DNA and RNA concentration in flight and synchronous experiment animals, as compared to the vivarium control. We failed to demonstrate differences between parameters of animals used in the flight and synchronous experiments, although there was definitely a tendency toward an increased effect in the flight variant. Changes in nucleic acid metabolism was one of the essential causes of change in tissue levels of nucleic acids. For this reason, we tested the intensity of DNA and RNA biosynthesis in liver nuclei. The results, which are listed in Table 2, revealed that the rate of biosynthesis of nuclear DNA decreased by 22 and 31% 6 days after termination of experiments in the synchronous and flight variants, as compared to 6 h. The effect was also manifested in RNA biosynthesis, but to

a lesser extent in the flight experiment than in the synchronous one (28% versus 46%). We cannot rule out the possibility that the decreased intensity of nucleic acid biosynthesis in the readaptation period is attributable to development of stress, which appears with the change from weightlessness to earth's gravity. This readaptation stress is, so to speak, additional to the stress experienced in flight or under the conditions of the synchronous experiment. Immobilization elicited depression of DNA and RNA synthesis in isolated liver nuclei of control animals to about one-half. After the flight and synchronous experiments, there was virtually no change in sensitivity of DNA biosynthesis to immobilization stress, as compared to the vivarium control. At the same time, postflight reactivity of DNA biosynthesis was diminished (the differences between the results in the third and first groups are statistically unreliable). The actually maximum decline of RNA biosynthesis in liver nuclei of animals used in the synchronous and flight variants of the experiment occurred already in the period of development of readaptation reactions to absence of immobilization (second group), and the effect was more marked in the synchronous experiment than the flight one. Immobilization showed no effect on already existing changes. This could be related to the fact that, under flight and synchronous experiment conditions, the systems responsible for RNA biosynthesis experienced a sort of "depletion." It is known that when a physiological system is submitted to some active factor, its repeated effect is attenuated. An analogous situation exists when the system is successively exposed to factors that have the same mechanisms of effects. Apparently, the effect diminishes more if the preceding factor was stronger. Consequently, it can be assumed that development of stress of the same nature preceded immobilization stress in animals from flight and synchronous experiments. After the flight, the changes were more marked, apparently due to the long exposure to weightlessness in space.

Table 2. Intensity of incorporation of radioactive precursors in nucleic acids of isolated liver nuclei ($M \pm m$)

Variant	Group	Specific activity, counts/min/ µg			
		DNA		RNA	
Vivarium control	1	$98,9 \pm 4,1$		2321 ± 460	
	2	$96,5 \pm 5,8$		2040 ± 170	
	3	$47,4 \pm 2,2$		1060 ± 273	
			$P_1 < 0,001$ $P_2 < 0,001$		$P_1 < 0,05$ $P_2 < 0,005$
Synchronous experiment	1	$106 \pm 5,2$		2764 ± 622	
	2	$83,2 \pm 5,9$		1503 ± 120	
			$P_1 < 0,05$		$P_1 < 0,05$
	3	$48,7 \pm 2,0$		1250 ± 205	
			$P_1 < 0,001$ $P_2 < 0,001$		$P_1 < 0,05$
Flight	1	$101,1 \pm 3,7$		2574 ± 401	
	2	$70,0 \pm 4,4$		1842 ± 296	
			$P_1 < 0,01$		$P_1 > 0,05$
	3	$49,3 \pm 1,9$		2011 ± 257	
			$P_1 < 0,001$ $P_2 < 0,01$		$P_1 > 0,05$

Our data indicate that, under these experimental conditions, there is no direct relationship between stress-induced "concentration" of nucleic acids and intensity

of biosynthesis thereof. However, it is quite likely that an indirect link exists between changes in these parameters. Indeed, intensification of dystrophic signs in the liver could be due to depressed RNA biosynthesis, since the protein level in cells is largely determined by transcribing activity of chromatin DNA.

Our findings indicate that, under the effect of spaceflight factors, there is some depletion of compensatory mechanisms, which maintain the normal level of metabolic processes in cells, in the animals' spleen and liver.

A comparative analysis of the results of synchronous and flight variants of the experiment warrants the belief that the weightlessness factor in space plays some part in development of the stress reaction in flight and during the recovery period on earth. The findings we obtained here and data in the literature [12, 13] warrant the conclusion that nucleic acids play a dissimilar role in reactions of different tissues and cells to spaceflight factors.

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EFFECT OF EXCESSIVE PHOSPHORUS INTAKE ON SOME ASPECTS OF PHOSPHORUS-CALCIUM METABOLISM AND CONDITION OF BONE TISSUE IN HYPOKINETIC RATS

[Article by M. S. Belakovskiy, N. V. Blazheyevich, V. B. Spirichev, I. N. Sergeyev and N. Ye. Spitsyna]

[English abstract from source] The exposure of rats fed with the diet containing Ca:P = 1:0.5-1:3 to hypokinesia produced by hypocalciemia, osteoporosis and increased renal calcinosis. The reduced phosphorus consumption (Ca:P = 1:0.5-1:1) prevented these disorders in the intact animals and increased bone density in the hypokinetic rats. The excessive phosphorus consumption caused hypocalciemia, hyperphosphatemia and slight osteoporosis in both intact and hypokinetic rats, with the changes being more pronounced in those latter. It is concluded that the diet with Ca:P = 1:0.5-1:1 is optimal for hypokinetic rats.

[Text] In accordance with the "Recommended Physiological Requirements for Nutrients and Energy," currently in effect in our country, the Ca requirement of adult man is set at 300 mg/day and P from 1200 to 1600 mg/day, i.e., the Ca/P ratio of 1:1.5-2.0 in the food allowance is considered optimal [1]. In the United States, a Ca/P ratio of 1:1 is considered optimum for adults and 1.5-1.25:1.0 for children according to the recommendations of the Food and Nutrition Service [2]. At the same time, the actual diet of modern man has a Ca and P ratio shifted in the direction of more P. Thus, in the diet of the U. S. population, Ca:P constitutes an average of 1:2.8 [3], and in the diet of inhabitants of Kazakhstan it is 1:3.9-4.1 [4]. Such foods as meat, fish, bread and bakery products are particularly rich in P and poor in Ca [5].

Several studies have demonstrated the role of excessive P intake in development of hyperphosphatemia, hypocalcemia, osteoporosis and calcinosis of soft tissues, with predominant involvement of kidneys in intact animals and man [6-12]. Long-term restriction of motor activity and immobilization lead to similar disturbances of phosphorus-calcium metabolism and osseous tissue [13]. For this reason, it is definite interest to determine the optimum proportion of Ca and P in the diet under hypokinetic conditions, since there could be enhancement of the effect of excessive P intake under such conditions.

Methods

The experiment was conducted on male Wistar rats weighing 200–250 g. The animals received a semisynthetic diet consisting of the following (percentages): casein-- 22, starch--56, sunflower oil--10, filter paper--3, salt mixture without Ca and P--0.5, $CaCO_3$--1.4, mixture of water-soluble vitamins--0.1, choline chloride-- 0.2 and salt supplements--6.8.

Ca content was the same in all allowances, and it constituted 0.6% (including level thereof in casein and $CaCO_3$ supplement), which corresponded to the optimum standard for intake of this mineral by rats. The phosphorus content of the diet (0.3, 0.6, 1.2 and 1.8%) was varied by adding the required amounts of $K_2HPO_4 \cdot 3H_2O$ and $NaH_2PO_4 \cdot 2H_2O$ in an equimolar proportion. K and Na content was equalized in all of the food allowances by addition of necessary amounts of $KCOOCH_3$ and $Na_3C_6H_5O_7 \cdot 5.5H_2O$ in a molar proportion of 6:1.

The salt mixture without Ca and P contained (in grams per kg feed allowance): $MgSO_4$ (anhydrous)--3.6, $ZnSO_4 \cdot 7H_2O$--0.088, $FeSO_4 \cdot 7H_2O$--0.124, $CuSO_4 \cdot 5H_2O$--0.02, $MnSO_4 \cdot 5H_2O$--0.214, NaCl--0.84, NaF--0.02, $CoCl_2 \cdot 6H_2O$--0.001, $(NH_4)_6 Mo_7O_{24} \cdot 4H_2O$-- 0.001, KI--0.001. The mixture of water-miscible vitamins contained the follow- ing elements (%): thiamin--0.5, riboflavin--0.5, pyridoxine--0.5, calcium panthothenate--2.0, nicotinic acid--2.0, folic acid--0.1, vicasol [vitamin K]-- 0.1, biotin--0.01, cyanocobalamine--0.002, glucose--94.3. Of the fat-soluble vitamins, the diet included vitamin A (5 mg retinyl acetate/kg diet), which was added to the sunflower oil. No vitamin E or D was added to the diet, since the former is present in sufficient quantity in sunflower oil and the latter in casein. Vitamin K was given in the form of vicasol as part of the water- soluble vitamins.

Each group of animals kept on a diet with a specific proportion of Ca and P was divided into two subgroups: the first subgroup consisted of control animals and the second, hypokinetic animals. Hypokinesia was produced by keeping the animals in compression cages. The experiment lasted 30 days.

After sacrificing the animals at the end of the experiment, we assayed concen- tration of Ca, inorganic P, activity of alkaline phosphatase in blood serum and Ca content of the kidneys [12, 14]. To assess the condition of bone tissue, we determined the specific weight of femoral diaphyses, and we assayed calcium, phosphorus and hydroxyproline levels in femoral diaphyses and epiphyses [12, 14].

Results and Discussion

Under our experimental conditions, excessive intake of P (Ca:P = 1:3) elicited a reliable decrease in weight gain of control animals. In hypokinetic rats, this parameter declined progressively with increase in P content in the diet (Table 1).

Table 2 lists data on Ca, P content and alkaline phosphatase activity in blood serum.

The increase in P content in the diet elicited some decrease in blood Ca con- centration in control animals, and this is consistent with previous findings

[8, 9]. Hypokinesia was associated with hypocalcemia with all tested Ca and P proportions in the diet; however, with the diet where Ca:P = 1:3, there was no marked decrease in blood serum Ca concentration, as compared to the corresponding control group. Probably, in this experiment, excessive intake of P per se elicited hypocalcemia. Intensification of hypocalcemia, as well as development of nephrolithiasis and urolithiasis, could have been one of the causes of death of three animals, which were submitted to hypokinesia and whose diet contained the above Ca:P ratio.

Table 1.
Effect of different P levels in diet on weight gain and Ca content of kidneys of hypokinetic rats

Animal group	Ca:P in diet	Weight gain, %, in 30-day experiment	Renal Ca, mg/g dry tissue
Control	1:0.5 (10)	40.7±3.9	0.7±0.05
	1:1 (11)	44.3±9.0	1.0±0.05
	1:2 (10)	40.5±5.7	2.4±0.3 $P_2 < 0.001$
	1:3 (11)	27.0±3.3 $P_2 < 0.02$	24.6±3.9 $P_2 < 0.001$
Hypo-kinesia	1:0.5 (10)	9.7±3.2 $P_1 < 0.01$	0.9±0.1
	1:1 (10)	3.6±4.2 $P_1 < 0.002$	1.3±0.2 $P_1 > 0.05$
	1:2 (9)	−9.6±4.7 $P_1 < 0.001$: $P_3 < 0.01$	3.0±0.6 $P_1 > 0.05$: $P_3 < 0.01$
	1:3 (7)	−14.8±7.4 $P_1 < 0.001$ $P_3 < 0.01$	17.2±3.5 $P_3 < 0.001$

Note: Here and in Tables 2-4: number of readings in parentheses, P_1--reliability of differences between hypokinetic and corresponding control, P_2--as compared to control given diet with Ca:P=1:0.5, P_3--as compared to hypokinetic group on diet with Ca:P=1:0.5.

There was no reliable change in blood serum P concentration in control animals. Under hypokinetic conditions, there was insignificant increase in its concentration in blood serum in animals fed a diet with high P content (Ca:P = 1:2).

Blood serum alkaline phosphatase activity did not change reliably in control animals. In hypokinetic rats, there was a tendency toward some decline in activity of this enzyme. Probably, this parameter does not reflect the correlation between processes of resorption and mineralization of bone tissue under these conditions. Blood alkaline phosphatase level is determined by migration of this enzyme not only from bone, but other tissues.

Table 1 lists data on Ca content of kidneys of experimental animals. A diet with excessive P content (Ca:P = 1:3) led to renal calcinosis in both groups, which is consistent with previous findings [8, 9]. Hypokinesia did not cause accumulation of Ca in kidneys of animals given a diet with balanced Ca and P content (Ca:P = 1:0.5-1:1) and did not reliably intensify renal calcinosis in animals on diets with Ca:P = 1:3 and 1:2. At the same time, some animals submitted to hypokinesia and fed a diet with Ca:P = 1:2 and 1:1 presented somewhat greater accumulation of Ca in the kidneys, which is indicative of the possibility of development of nephrocalcinosis under hypokinetic conditions.

Tables 3 and 4 list data on condition of experimental animals' osseous tissue.

Hypokinesia led to development of osteoporosis, which was manifested by a decrease in specific weight of bone tissue and levels of Ca, P and hydroxyproline in it (scaled to the unit of volume and weight). These changes progressed with increase in P content in the diet, and they were the most marked in animals

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given excessive amounts of P. A decrease in P intake prevented development of osteoporotic changes in control animals and increased mineralization of osseous tissue in hypokinetic rats.

Table 2. Effect of different amounts of P in diet on levels of Ca, P and activity of alkaline phosphatase in blood serum of hypokinetic rats

Animal group	Ca:P in diet	Ca, mg/100 ml	P, mg/100 ml	Alkaline phosphatase IU/l(37°C)
Control	1:0,5 (10)	9,6±0,1	10,2±0,2	87,0±4,3
	1:1 (11)	9,1±0,2	0,1±0,3	84,6±8,7
	1:2 (10)	8,9±0,1 $P_2<0,001$	8,9±0,1	72,0±4,5
	1:2 (11)	7,9±0,1 $P_2<0,001$	11,5±0,3	9,8±7,1
Hypokinesia	1:0,5 (10)	8,2±0,1 $P_1<0,001$	9,7±0,2	67,5±0,4 $P_1<0,01$
	1:1 (9)	8,1±0,15 $P_1<0,001$	9,8±0,6	77,0±9,0
	1:2 (8)	8,0±0,3 $P_1<0,02$	10,1±0,3 $P_1<0,002$	72,6±7,8
	1:3 (7)	7,7±0,2 $P_3<0,05$	10,9±0,7	72,6±6,1 $0,05<P<0,1$

Table 3. Effect of different amounts of P in diet on specific weight of femoral diaphyses in hypokinetic rats

Animal group	Ca:P in diet	Specific weight, g dry tissue per cm³	Ca, mg/cm³	P, mg/cm³	Hydroxy-proline, mg/cm³
Control	1:0,5 (17)	1,65±0,03	440±11	267±6	37,0±1,3
	1:1 (19)	1,65±0,02	436±10	268±8	36,5±1,1
	1:2 (17)	1,67±0,02	433±12	271±5	37,4±1,1
	1:3 (19)	1,61±0,02	396±11 $P_2<0,01$	254±5 $0,05<P_2<0,1$	34,7±1,1 $P_2>0,05$
Hypokinesia	1:0,5 (17)	1,43±0,02	340±9	218±4	28,7±0,7
	1:1 (17)	1,40±0,02	337±10	216±5	26,0±1,0
	1:2 (13)	1,41±0,01	321±10	216±4	26,8±1,0
	1:3 (11)	1,40±0,02	304±12 $P_3<0,02$	212±4	25,4±1,0 $P_3<0,02$

The Ca:P ratio in femoral diaphyses and epiphyses diminished under hypokinetic conditions, and with increase in P content of the diet it diminished progressively: from 1.65 to 1.56 in diaphyses and from 1.70 to 1.66 in epiphyses of intact animals, from 1.56 to 1.43 and from 1.63 to 1.53, respectively in hypokinetic rats. The decline of Ca:P under hypokinetic conditions and with excessive intake of P could have occurred as a result of an increased amount of amorphous phase of calcium phosphate in bone tissue.

Table 4. Effect of different amounts of P in diet on composition of femoral epiphyses of hypokinetic rats (in mg/g dry tissue)

Animal group	Ca:P in diet	Ca	P	Hydroxy-proline
Control	1:0,5 (17) 1:1 (19) 1:2 (17) 1:3 (19)	211±2,8 209±2,6 210±3,9 199±2,3 $P_2<0,01$	124±2,2 125±1,8 125±2,8 120±2,0	23,5±0,6 23,0±0,6 22,8±0,9 20,9±0,8 $P_2<0,01$
Hypokinesia	1:0,5 (17) 1:1 (17) 1:2 (13) 1:3 (11)	184±4,7 182±1,7 176±3,6 169±5,5 $P_3<0,05$	113±1,5 115±1,0 114±1,8 110±2,7	20,4±0,9 20,7±0,5 19,5±0,7 18,9±0,7 $0,05<P_1<0,1$; $P_3>0,05$

There was no appreciable change in proportion of Ca and hydroxyproline in diaphyses and epiphyses of experimental animals and this, along with the decline in both calcium and hydroxyproline, is indicative of development of changes in bones of the osteoporosis type.

The changes in bone under conditions of weightlessness affect primarily the epiphyses and metaphyses of long bones [15]. The ratio of Ca and P content of diaphyses to Ca and P content of epiphyses diminished somewhat in hypokinetic rats (1.28-1.32 and 1.34-1.37, respectively; in control animals the figures were 1.23-1.27 and 1.30-1.31). These data could be indicative of resorption and/or decrease in calcification of epiphyses, as compared to diaphyses, in hypokinetic rats, as well as some redistribution of Ca and P within the same bone, as shown by A. A. Prokhonchukov [15].

Thus, as indicated by our results, excessive intake of P (Ca:P = 1:3) leads to hypocalcemia, development of nephrocalcinosis and insignificant changes in bone tissue of the osteoporosis type in intact animals. These disturbances could be attributable both to direct decrease in Ca absorption in the intestine in the presence of excessive P and change in production in the kidneys of active metabolites of vitamin D (1,25 and 24,25-dihydroxycholecalciferol) and development of secondary hyperparathyroidism.

In hypokinetic rats, we observed a decrease in blood concentration of Ca and development of osteoporosis with all tested Ca:P ratios in the diet, as well as come increase in renal calcinosis in animals fed diets with Ca:P = 1:1-1:3. At the same time, a decrease in P intake (Ca:P = 1:0.5-1:1) prevented development of these disturbances in intact animals and increased mineralization of bone in hypokinetic ones. Evidently, the optimum Ca:P ratio is 1:0.5-1.1 under hypokinetic conditions.

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ROLE OF 24,25-DIHYDROXYCHOLECALCIFEROL IN BONE MINERALIZATION IN HYPOKINETIC RATS

[Article by I. N. Sergeyev, N. V. Blazheyevich, M. S. Belakovskiy, V. B. Spirichev
and A. S. Ushakov]

[English abstract from source] 24,25-Dihydroxycholecalciferol,
and active D_3 vitamin metabolite, at a dosage of 1.25 μg/day/
animal prevents bone osteoporotic changes, effectively stimulating
the diaphyseal and epiphyseal mineralization, and corrects hypo-
calciemia of hypokinetic rats. $24,25(OH)_2D_3$ at the above dose
does not increase nephrocalcinosis or does not produce the toxic
effect as measured by body mass variations.

[Text] Prolonged restriction of movement and immobilization lead to impairment
of phosphorus-calcium metabolism and condition of bone tissue of man and
animals, which is similar to the disturbances observed during long-term space-
flights [1, 2].

Ca and P metabolism is largely regulated by vitamin D [3-5]. The hormonally
active form—1,25-dihydroxycholecalciferol ($1,25(OH)_2D_3$), or calcitriol—per-
forms the functions of this vitamin, and it has a direct, stimulating effect
on bone tissue resorption [3, 5]. On the other hand, 24,25-dihydroxychole-
calciferol ($24,25(OH)_2D_3$) may have a specific function, manifested by a direct
stimulating effect on formation and mineralization of osseous tissue [6-10].

For this reason, it was deemed interesting to explore the possibility of correct-
ing phosphorus and calcium metabolism and preventing bone disturbances under
hypokinetic conditions by means of giving animals supplemental $24,25(OH)_2D_3$.

Since excessive P in the diet enhances the effect of hypokinesia on phosphorus
and calcium metabolism [11] and alters production in the body of active
metabolites of vitamin D [3], we tested the effect of $24,25(OH)_2D_3$ with use
of diets with different Ca and P ratios.

Methods

The experiments were conducted on male Wistar rats weighint 200-250 g. The
animals were given a semisynthetic diet, the composition of which has been

described previously [11, 12]. Ca content was the same in the food allowance of animals in all groups, constituting 0.6%; P content constituted 0.3, 0.6, 1.2 or 1.8%. Thus, the animals were given a diet with Ca:P = 1:0.5, 1:1, 1:2 and 1:3. Each group of animals given a diet with a specific Ca:P ratio was divided into 3 subgroups with 10-12 animals in each: the first subgroup consisted of control animals (whose movements were not restricted); the second of animals kept under hypokinetic conditions and the third of animals kept under hypokinetic conditions and given $24,25(OH)_2D_3$ throughout the experimental period. Hypokinesia was produced by keeping animals in compressive cages.

$24,25(OH)_2D_3$ (mixture of 24R and 24S epimers)* was given to the rats daily in a dosage of 1.25 µg/animal/day in 0.1 ml propylene glycol. This dosage is equivalent to 5 times the physiological dose of vitamin D_3 for rats.

The rats were kept in hypokinetic cages for 30 days. After decapitating them at the end of the experiment, we assayed Ca concentration, inorganic P, alkaline phosphatase activity in blood serum and Ca content in the kidneys [11, 12]. In order to evaluate the condition of osseous tissue, we determined the specific weight of femoral diaphyses and assayed Ca, P and hydroxyproline in femoral diaphyses and epiphyses [11, 12].

Results and Discussion

Under our experimental conditions, $24,25(OH)_2D_3$ had no toxic effect, as assessed by change in animals' weight. The weight of rats given this product was consistently higher than in hypokinetic animals. On the 30th day, this increase constituted 3.6-14.0% and was at a maximum in animals given a diet with Ca:P = 1:2-1:3.

In rats kept under hypokinetic conditions, $24,25(OH)_2D_3$ corrected hypocalcemia (see Table). As compared to control animals, blood Ca level constituted 92-110% with the use of this product.

No appreciable effect was noted of $24,25(OH)_2D_3$ on P content and alkaline phosphatase activity in blood serum of experimental animals.

Use of $24,25(OH)_2D_3$ did not intensify renal calcinosis in hypokinetic rats (see Table).

Figures 1-3 illustrate data on condition of bone tissue of experimental animals. Demineralization of bone was effectively prevented by $24,25(OH)_2D_3$. As compared to control animals, Ca and P content of femoral diaphyses constituted 91-98 and 96-104% with use of this product, the levels thereof in femoral epiphyses and specific weight of the femur also increased.

The proportion of Ca and P in diaphyses and epiphyses diminished under hypokinetic conditions; with use of $24,25(OH)_2D_3$, there was normalization of the ratio in the epiphyses. In the diaphyses, Ca:P ratio remained lower than in control animals, but reliably higher than in hypokinetic animals.

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*The preparation of 24R, S, $25(OH)_2D_3$ was synthesized and kindly provided to us by N. A. Bogoslovskiy, senior scientific associate at the "Vitaminy" Research Production Association, for which we express our sincere appreciation.

Effect of $24,25(OH)_2D_3$ on Ca content of blood serum and kidneys of hypokinetic rats kept on diets with differing Ca:P ratios

Animal group	Ca:P in diet	Ca content	
		serum, mg/100ml	kidneys, mg/g dry tissue
Control	1:0,5	$9,6\pm0,1$	$0,7\pm0,05$
	1:1	$9,1\pm0,2$	$1,0\pm0,05$
	1:2	$8,9\pm0,1$	$2,4\pm0,3$
		$P_3<0,001$	$P_3<0,001$
	1:3	$7,9\pm0,1$	$24,6\pm3,9$
		$P_3<0,001$	$P_3<0,001$
Hypokinesia	1:0,5	$8,2\pm0,1$	$0,9\pm0,1$
		$P_1<0,001$	
	1:1	$8,1\pm0,15$	$1,3\pm0,2$
		$P_1<0,001$	$P_1>0,05$
	1:2	$8,0\pm0,3$	$3,0\pm0,6$
		$P_1<0,02$	$P_1>0,05$
	1:3	$7,7\pm0,2$	$17,2\pm3,5$
		$P_4<0,05$	
Hypokinesia + 24,25 $(OH)_2D_3$	1:0,5	$8,8\pm0,2$	$0,6\pm0,02$
		$P_2<0,02$	
	1:1	$8,5\pm0,2$	$0,8\pm0,02$
		$0,05<P_2<0,1$	
	1:2	$8,6\pm0,3$	$2,2\pm0,5$
		$P_2>0,05$	
	1:3	$8,7\pm0,2$	$19,6\pm4,0$
		$P_2<0,002$	

Note: Here and in Figures 1-3, the following reliabilities of differences are given:

P_1--for animals submitted to hypokinesia, as compared to parameters for corresponding group of control animals

P_2--for animals given $24,25(OH)_2D_3$, as compared to corresponding group submitted to hypokinesia

P_3--for rats in the control group, as compared to animals in control group on diet with Ca:P = 1:0.5

P_4--for animals submitted to hypokinesia, as compared to parameters of hypokinetic animals on diet with Ca:P = 1:0.5

The results warrant the conclusion that $24,25(OH)_2D_3$ prevents bone changes and hypocalcemia in hypokinetic rats, which is indicative of the role of this active form of vitamin D_3 in the pathogenesis of Ca and P metabolic disturbances under hypokinetic conditions.

The bone changes in weightlessness are referable primarily to epiphyses and metaphyses of long bones [2]. At the same time, with use of $24,25(OH)_2D_3$, there was fuller restoration of calcium and phosphorus content expressly in epiphyses. The ratio of Ca content of the diaphyses to Ca content of epiphyses under hypokinetic conditions increased somewhat (1.28-1.32, versus 1.23-1.27 in control animals). Use of $24,25(OH)_2D_3$ reduced this ratio to 1.16-1.18, i.e., $24,25(OH)_2D_3$ effectively stimulated accumulation of calcium in epiphyses. The analogous ratio for P also increased under hypokinetic conditions (1.34-1.37, versus 1.30-1.31 in the control), and intake of $24,25(OH)_2D_3$ normalized this ratio (1.27-1.33).
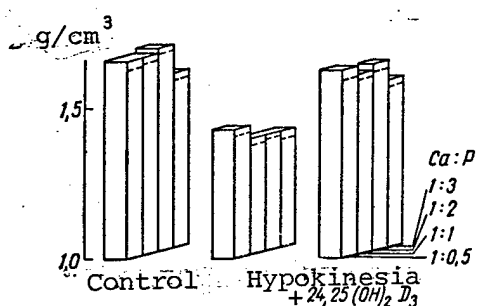
Figure 1.
Effect of 24,25(OH)$_2$D$_3$ on specific
weight of femur in hypokinetic rats
  Here and in Figures 2 and 3, the
  reliability of differences between
  mean values of specific weight is
  given for P$_1$ and P$_2$<0.05. The
  dotted line shows standard error.
  P$_5$--reliability of differences be-
      tween animals submitted to hypo-
      kinesia and given 24,25(OH)$_2$D$_3$,
      and hypokinetic rats given
      24,25(OH)$_2$D$_3$ on diet with
      Ca:P = 1:0.5

Our data may be indicative of the spe-
cific effect of 24,25(OH)$_2$D$_3$ on minera-
lization of bone. This effect of
24,25(OH)$_2$D$_3$ is probably attributable
to the fact that this metabolite of
vitamin D$_3$ stimulates Ca absorption
just as actively in the intestine as
1,25(OH)$_2$D$_3$, but unlike the latter
has no resorptive effect on bone [10,
13, 14]. Moreover, there are data to
the effect that 24,25(OH)$_2$D$_3$ is capable
of stimulating osteogenetic processes
in vitamin D deficient animals [6-10].

It should be stressed that the effect
of 24,25(OH)$_2$D$_3$ observed in this ex-
periment was pharmacological. Adminis-
tration of large doses of this product
in a nonphysiological way could create
a high concentration of 24,25(OH)$_2$D$_3$ in
receptor regions for metabolites of
vitamin D$_3$ and thus elicit activation
of processes regulated by this vitamin
under physiological conditions. More-
over, the stimulating effect of
24,25(OH)$_2$D$_3$ on Ca absorption in the intestine is apparently related to its
prior 1α-hydroxylation [13] or else it is attributable to increased synthesis of
1,25(OH)$_2$D$_3$ when this metabolite is given [3, 15]. However, when given by
mouth, 24,25(OH)$_2$D$_3$ can apparently have a direct effect on the intestinal mucosa,
enhancing Ca absorption [14]. Administration of 24,25(OH)$_2$D$_3$ can also reduce
parathyroid hormone secretion [4].

Figure 2.
Effect of 24,25(OH)$_2$D$_3$ on chemical com-
position of femoral diaphyses in hypo-
kinetic rats. Reliability of difference
between subgroup parameters: for Ca,
P$_3$<0.01, P$_4$<0.02, P$_5$<0.05; for P,
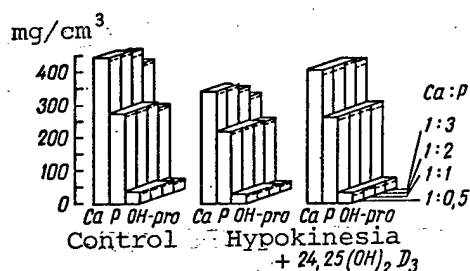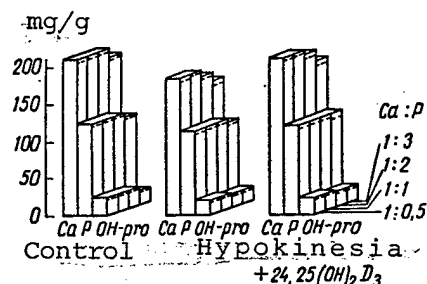0.05<P$_3$<0.1; for hydroxyproline,
P$_3$>0.05, P$_4$<0.02

Figure 3.
Effect of 24,25(OH)$_2$D$_3$ on chemical com-
position of femoral epiphyses in hypo-
kinetic rats. Reliability of differ-
ences between the same subgroup para-
meters: for Ca, P$_3$<0.01, P$_4$<0.05,
P$_5$<0.01; for hydroxyproline, P$_3$<0.01,
P$_4$>0.05

The effect of excessive phosphorus on vitamin D metabolism could also be mediated by changes in blood Ca and P concentrations [16]. Hypocalcemia activates $25(OH)D_3-1\alpha$-hydroxylase in the kidneys, whereas increased uptake of P and hyperphosphatemia lead to decline of $1,25(OH)_2D_3$ in blood. Under physiological conditions (normocalcemia, normophosphatemia), $14,25(OH)_2D_3$ is the main circulating form of dihydroxy derivatives of vitamin D_3. Its concentration in plasma is 100 times higher than the level of $1,25(OH)_2D_3$, whereas its half-life is 15-40 days, versus 1-3 days for $1,25(OH)_2D_3$ [15].

In an analogous experiment using 1α-hydrocholecalciferol ($1\alpha(OH)D_3$), the synthetic analogue of calcitriol, it was shown that keeping rats in restrictive cages, which limit their motor activity but do not immobilize them, elicits less marked disturbances in phosphorus and calcium metabolism [11]. Administration of physiological doses of $1\alpha(OH)D_3$, which normalized blood Ca level, did not prevent resorption of bone and enhanced calcinosis of the kidneys and aorta. This effect of $1\alpha(OH)D_3$ is attributable to the action of $1,25(OH)_2D_3$, which is formed from it in the body [3].

Our findings are indicative of the desirability of using $24,25(OH)_2D_3$ in doses equaling 5-10 times the physiological doses of vitamin D_3, in the combined prevention and therapy of disturbances in mineral metabolism under hypokinetic conditions. In the presence of marked hypocalcemia, it is possible to additionally give physiological doses of $1\alpha(OH)D_3$ or calcitriol in order to effectively normalize absorption of Ca in the intestine. It is desirable to use the above metabolites of vitamin D_3 in combination with measures to lower uptake [or intake] of P and normalize its level in blood.

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AUTONOMY OF OTOLITHIC NYSTAGMUS CENTERS

[Article by Yu. K. Stolbkov]

[English abstract from source] Pigeons (Columba livia) with unilaterally sectioned saccular nerves (Ramuli sacculi) were rotated in the dark along the horizontal plane. The nystagmic reaction which developed when the vestibular apparatus was simultaneously exposed to otolith and canal stimuli, each of which taken separately caused nystagmus of the same direction, was less pronounced in the case of canal stimulation. This can be regarded as evidence indicating autonomicity of otolith nystagmus centers

[Text] It is not only of theoretical, but great practical importance to study the mechanisms of vestibular nystagmus (VN), since VN is used extensively in clinical practice, as well as aviation and space medicine as a diagnostic sign. Vestibular function is assessed by means of the VN in professional screening, training, etc. [1-6]. According to data in the literature, VN occurs as a result of stimulation of receptors of semicircular canals, while stimulation of otolith organs leads to various changes in this nystagmus [7-10]. However, we have demonstrated that, under certain conditions, stimulation of receptors not only of VN but otolith organs leads to nystagmus [11]. Our objective here was to determine what stimulates otolithic nystagmus (ON)[1]: the same nerve centers, excitation of which upon stimulation of semicircular canals leads to nystagmus, or different pathways and centers for otolithic and canal nystagmus?

Methods

Pigeons (Columba livia), submitted to unilateral transection of saccular nerves (ramuli sacculi)[2], were immobilized in a special stand and rotated on a stand with programmed control [12]. The lateral semicircular canals were in the plane of rotation. The birds were rotated in the dark on a trapezoid program: positive angular acceleration of $20°/s^2$, rotation at a constant angular velocity of $166°/s$ for 2 min (plateau), negative angular acceleration of $20°/s^2$. With centric rotation, the axis of rotation passed between the labyrinths.
In this case, we recorded nystagmus caused by stimulation of semicircular canal receptors. With eccentric rotation, the effect of positive angular acceleration

was associated with increase in centrifugal acceleration from 0 to 0.5 G. During rotation on a plateau, centrifugal acceleration remained constant, and it decreased from 0.5 G to 0 under the influence of negative angular acceleration; centrifugal force was in the tail-head direction. R ceptors of the semicircular canals and otolith organs were stimulated simultaneously during acceleration and deceleration; only otolith organ receptors were simulated on the plateau. We alternated centric and eccentric rotations (12 each); with each form, the pigeons were rotated on a trapezoid program, first to the right (one "trapezium") and then to the left (one "trapezium").

Cervical nystagmus was recorded on an N-117 loop oscillograph; bioelectric potentials were picked up with silver needle electrodes from the left and right m. rectus capitis posticus major; a Disa 13-A-69 electromyograph was used to amplify bioelectric potentials.

We conducted a total of 14 experiments with 14 pigeons. They were performed on the day after unilateral transection of saccular nerves. The technique for severing individual branches of the vestibular nerve was described in detail previously [13, 14].

Results and Discussion

During positive angular acceleration and clockwise rotation (to the right) the pigeons demonstrated regular muscular activity in the left muscle, and with negative acceleration in the right one (see Figure, 1). With change in direction of rotation, positive angular acceleration elicited a reaction in the right muscle and negative acceleration did so in the left (see Figure, 2). The recorded activity was in the form of volleys corresponding to slow components of cerfical nystagmus, which alternated with periods of rest.[3] During centric rotation at constant angular velocity there was no nystagmus (see Figure, 1 and 2). With eccentric rotation on a plateau, ON was observed in the direction of the intact labyrinth; its direction was unrelated to the direction of rotation (see Figure, 3 and 4).
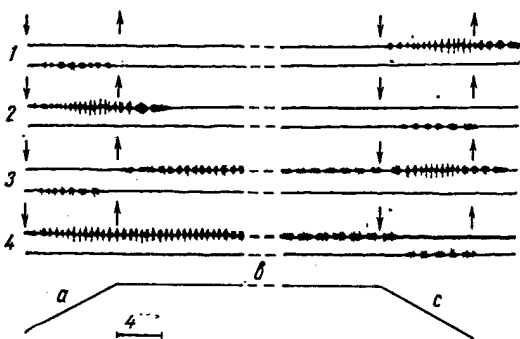
Reaction of cervical muscles to rotation on trapezoid program in pigeon with unilaterally transected right saccular nerve. Time mark 4 s. Trapezoid rotation test scheme shown at the bottom:

a) period of positive angular acceleration
b) plateau
c) period of negative angular acceleration
1,2) centric rotation
3,4) eccentric rotation
1,3) rotation to the right
2,4) rotation to the left
Top curves: EMG of right muscle
Bottom curves: EMG of left muscle

Appearance of nystagmus in response to otolith stimulation (in the absence of stimuli directed at the semicircular canals) does not necessarily indicate that there are autonomous ON centers. Perhaps, otolith afferentation is merely

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instrumental in manifestation of the reaction related to the semicircular canals. In other words, it is quite probable that, under certain conditions, stimulation of otolith organs elicits the same changes in nystagmogenic centers of the semicircular canals as stimulation of receptors of these canals.

Mean values of some quantitative parameters of cervical nystagmus in pigeons submitted to negative angular acceleration (M±m)

Pigeon No	Nystag param.	Stimulated part		Pigeon No	Nystag param.	Stimulated part	
		SC	SC & OO			SC	SC & OO
1	RT	15,5±0,21	12,2±0,17	8	RT	16,3±0,74	7,1±0,81
	F	30,7±1,68	18,0±1,31		F	19,7±0,67	13,3±0,54
2	RT	14,7±0,34	12,7±0,42	9	RT	16,5±0,76	15,1±0,48
	F	29,0±1,26	22,0±1,31		F	41,4±1,26	31,6±1,13
3	RT	14,5±0,22	8,0±0,11	10	RT	10,0±0,33	9,5±0,21
	F	14,3±0,42	6,5±0,44		F	10,0±0,37	6,4±0,91
4	RT	16,7±0,25	14,7±0,21	11	RT	12,3±0,33	10,4±0,21
	F	20,0±0,84	19,1±0,77		F	17,1±0,28	15,5±0,42
5	RT	11,9±0,29	11,9±0,32	12	RT	14,5±0,54	13,3±0,37
	F	21,7±0,91	20,4±0,77		F	39,1±1,64	37,2±1,34
6	RT	17,5±1,40	12,3±1,15	13	RT	7,5±0,21	5,0±0,11
	F	18,0±1,12	10,7±0,84		F	5,0±0,21	5,0±0,17
7	RT	17,3±0,63	14,8±0,33	14	RT	13,0±0,41	9,3±0,24
	F	24,0±0,47	18,5±0,95		F	11,0±0,44	7,5±0,42

Key: RT) reaction time   SC) semicircular canals
      F) frequency of jerks during reaction   OO) otolith organs

Note: Otolith and canal stimuli used separately elicited nystagmus in one direction.

According to data in the literature, VN occurs as a result of asymmetrical change in afferentation from receptors of symmetrical semicircular canals (increased afferentation from one labyrinth and decrease from the other). The greater the asymmetry of afferentation and, consequently, asymmetry of excitation of nerve centers related to semicircular canals, the more marked the nystagmic reaction; the direction of nystagmus is strictly related to changes in afferentation from semicircular canals[4] [3]. Nystagmus appears only with asymmetrical change in afferentation from symmetrical vestibular receptors [11]. Let us assume that both ON and CN [canal nystagmus] appear as the result of asymmetrical change in excitation in the same nerve centers. If this assumption is valid, the nystagmic reaction appearing with the concurrent effect on the vestibular system of otolith and canal stimuli, each of which elicits nystagmus in the same direction, should be more marked than the responses to either one of these stimuli. However, the reaction arising under the concurrent effect of stimuli eliciting responses in different directions should be less marked than the reaction to use of either one of the stimuli. Consequently, the result of comparing nystagmic reactions recorded upon stimulation of receptors of semicircular canals to those recorded with simultaneous stimulation of semicircular canals and otoliths enables us to answer the question, consideration of which was the purpose of this study. Since a change in magnitude of centrifugal acceleration—a stimulus leading to ON—occurs

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simultaneously with change in speed, one cannot determine exactly the time of appearance (or disappearance) of ON. For this reason, it would not be quite correct to compare reactions demonstrated under the combined effect of otolith and canal stimuli, which elicit reactions in different directions when used separately.[5] The reaction recorded under the concurrent effect of stimuli elicitng reactions in the same direction is also unsuitable for comparisons, if this reaction was demonstrated under the effect of positive angular acceleration, since in this case CN changes immediately to ON, which continues over the entire plateau (see Figure, 4). In order to solve our problems, apparently the suitable reaction is the one recorded with the concurrent effect of stimuli that elicit reactions in the same direction, if it appears with negative angular acceleration. In this case too, we do not know when ON stops. However, we know exactly the reaction time, which we consider cumulative,[6] in the first place, and, in the second place, that under the effect of negative angular acceleration the asymmetry of otolith afferentation diminishes to the base level, but its sign does not change.[7] On this basis, the cumulative [overall] reaction must be greater than the reaction recorded under the isolated effect of stimulation of semicircular canal receptors. However, as can be seen in the Table, in our experiments the quantitative parameters of the responses to simultaneous effects of stimuli, which elicit unidirectional reactions, not only were not higher, but usually lower than the same quantitative parameters of post-rotatory nystagmus under the effect of isolated stimulation of semicircular canals. Consequently, appearance of ON upon stimulation of otolith organs was unrelated to the fact that a change in otolith afferentation is instrumental in manifestation of the reaction of semicircular canals. These data indicate that the pathways and centers of otolithic and canal nystagmus are different.

Interaction between otolith and canal parts of the vestibular system can apparently occur in two ways. The first is interaction on the order of capture of the common end pathway: if two reactions from different parts of the vestibular system are projected on the same effector, there is no algebraic summation of these reactions on the effector, and only one of the responses is manifested. The other variant of interaction is inhibition of the response from the semicircular canals under the influence of otolith organs. This conclusion is quite valid. If interaction between the two parts of the vestibular system occurred only in the form of the first type, the duration of the overall reaction would not be any shorter than with isolated stimulation of the semicircular canals. In this case, otolith stimulation influences the CN centers. Thus, autonomy of ON and CN centers does not signify autonomy of the otolith and canal parts of the vestibular system. As indicated by our findings, the otolith part has a very definite (inhibitory) effect on CN. However, the pathways over which this influence is transmitted and the pathways over which ON occurs are apparently different.

FOOTNOTES

1. We use the term, otolithic nystagmus, to refer to nystagmus arising as a result of stimulating otolith organ receptors and canal nystagmus, to refer to nystagmus arising with stimulation of semicircular canal receptors.

2. In such pigeons, ON appears when otolith membranes shift in a nasal direction [11].

3. The periods of rest between volleys coincides in time with the fast components of cervical nystagmus. However, when the head is rigidly immobilized, it is rare to succeed in recording muscular activity from the contralateral muscle that would correspond to fast components [12].

4. For example, during rotation to the right in a horizontal plane, with positive angular acceleration there is prevalence of afferentation from the right lateral canal and horizontal nystagmus appears that is directed to the right [3].

5. We could conceive of the following situation: ON appears at the moment when the reaction from the semicircular canals stops. In this case, nystagmus recorded during the period of angular acceleration (with eccentric rotation) will generally not be the result of interaction between semicircular canals and otolith organs. Such a situation is quite possible, since it was demonstrated [14] that the duration of reactions to the operated side (with centric rotation) in pigeons with unilateral transection of saccular nerves could be shorter than the duration of acceleration.

6. As duration of this reaction, we took the interval from the start of negative angular acceleration to complete disappearance of nystagmus.

7. For example, if afferentation from the right labyrinth has become greater under the influence of otolith stimulation during rotation on a plateau than from the left, under the influence of negative angular acceleration there will be a decrease in asymmetry, which reaches zero, but never is this associated with a moment when the level of afferentation from the left becomes greater than from the right.

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DIRECT-READING DOSIMETERS USED FOR MONITORING RADIATION IN SALYUT STATIONS

[Article by V. V. Markelov and I. V. Chernykh]

[English abstract from source] Using PPD-2 dosimeters, daily radiation doses were measured in the same site of the Salyut-3, Salyut-4 and Salyut-5 stations (1974-1977). The doses were estimated to be about 13-16 mrad/day. During the flight of the Salyut-6 station (1977-1979) daily doses were measured in different sites and were found to vary significantly. By 1980, due to an increase in solar activity and lack of solar flares, the difference in the daily doses inside the station (except for the transfer module) reached the level of the error of measurements, i.e., ±20%.

[Text] At the present time, all manned space complexes (MSC) are equipped with dosimetry equipment, which makes up the system of dosimetric monitoring. The system consists of personnel and onboard instruments. The personnel dosimeters presently used in MSC consist of thermoluminescent glass and, from the standpoint of obtaining information, they are "passive," i.e., they are subject to postflight processing on the ground.

Onboard dosimetry instruments make it possible to obtain dosimetric information in flight at fixed places. As shown by dosimetry studies on an artificial earth satellite (AES) with apogee of up to 350 km [1], the dosage of cosmic radiation is nonuniformly distributed over the craft. The dose gradient is 3-5-fold, which rules out the possibility of considering the specifics of exposure of each cosmonaut. This gap in the system of radiation monitoring is well-filled by means of self-contained miniature dosimeters that directly display the current cumulative dose [2]. Such an instrument permits operational individual dosimetric monitoring, both in a normal situation and with worsening of the radiation conditions, monitoring of radiation conditions in the areas where the crew spends most of its time, as well as to make a collation map of dose fields in different modules of the MSC, implement operational dosimetric monitoring during extravehicular activity and use the readings of onboard dosimetry equipment for relative comparison.

The practice of manned spaceflights requires that the above-mentioned equipment have high performance qualities, the chief ones being low weight, small size,

wide range of recorded doses, convenience in making readings and long-term operation.

Methods

In recent years, the PPD-2 self-contained, direct-indicating research dosimeter has been used with success for dosimetric monitoring and studies of the radiation conditions aboard Salyut stations, and it has the following specifications: dimensions 128×68×23 mm, range of measured doses 10 mrad to 100 rad per cycle, continuous operating time with one set of self-contained power sources at least 1 year, range of reliable display of visual information at least 0.5 m, and margin of error in dose measurement does not exceed 20%.

The sensory of this instrument is an ionization chamber filled with a tissue-equivalent mixture of pressurized gases. In the chamber, the current is transformed into pulses by a gas-discharge transformer. After appropriate amplification, the pulses actuate an electromechanical counter with pointer-equipped dial. The instrument is powered by mercury-zinc elements.

The PPD-2 dosimeter was kept in a permanent site aboard Salyut-3, Salyut-4 and Salyut-5 stations, and it was used to measure mean daily radiation doses. A study was conducted aboard Salyut-6 station of the dynamics of accumulation of dosage in several points. This study was conducted using two direct-reading PPD-2 dosimeters, once of which had been operating from the start of work on this station and was returned to earth 21 months after the second instrument had been delivered by the Progress-6 transport craft. According to the program of radiation research, the dosimeter was moved within the station to specific points and left there for 4-10 days, which was sufficient time to gain reliable information. The choice of areas was determined by two factors: predominant location of the crew at a given point and difference in shielding by elements of the station. When necessary, information could be taken from the instrument at any time. Regular readings taken from the instrument made it possible to determine the mean daily doses during the mission, along with measurement of integral dose.

Results and Discussion

Table 1 lists the results of measurement of mean daily doses of cosmic radiation by PPD-2 instruments aboard the Salyut stations.

Table 1. Mean daily doses of cosmic radiation aboard Salyut stations

Station	Launch date	Mean daily dose mrad/day
Salyut-3	June 1974	15
Salyut-4	December 1974	13
Salyut-5	June 1976	15
Salyut-6	September 1977	16

As can be seen in Table 1, the mean daily doses, averaged for the entire period of investigation with the instrument in the same location, were virtually the

same in all stations, which is indicative of similarity of radiation conditions in these stations. Nevertheless, there could be differences in average daily doses in different areas in the station. The radiation situation had been studied quite well on the routes of the Salyut stations. The levels of radiation to which cosmonauts are exposed are attributable to constant sources: galactic cosmic radiation (GCR), radiation from earth's radiation belts (RERB), as well as solar cosmic rays (SCR). The flux of GCR [2] is quite stable during flights. The mean daily dosage from SCR constitutes 5-8 mrad/day in these orbits during periods of minimal solar activity. Radiation from the radiation belt within the station is a factor only in the area of the South Atlantic anomaly, and it is the decising factor in the absence of solar flares [3].

Table 2. Results of measurements of integral and mean daily doses aboard Salyut-6

| Instrument	Year and month of measurement	Mission	1 ID	1 MD	2 ID	2 MD	3 ID	3 MD	4 ID	4 MD	5 ID	5 MD
First	1977, December	First & second	1176	16.1	144	9.6	88	17.6	—	—	—	—
	1978: January		186	16.7	64	12.8	—	—	125	22.8	220	32.4
	March		—	—	—	—	—	—	408	13.6	—	—
	June		—	—	—	—	—	—	1685	14.7	—	—
	July		43	7.2	93	10	80	16	336	11.2	395	24.6
	August		—	—	77	15.4	80	16	—	—	267	24.3
	September		—	—	—	—	—	—	—	—	176	35.2
First	1979: March	Third	595	8,5	2361,8 / 99,4	14,4 / 7,1	—	—	—	—	—	—
	April		72	8,0*	—	—	—	—	59,5	8,5	143,6	13,3
	May		—	—	103,2	14,7	120,4	12,0	—	—	163,4	16,3*
	June		—	—	—	—	—	—	292,4	14,6*	—	—
Second	1979: June	Third	—	—	93	13,2	255	19,6*	225	22,5*	143,6	13,3
	July		—	—	—	—	—	—	—	—	225	22,5*
	August		198	18,0*	—	—	—	—	—	—	—	—
Second	1980: April	Fourth	3231	13,0	129	12,9	54	6,0	111	11,1	81	8,1
	May		—	—	—	—	80	8,0	—	—	—	—
	June		80	8,0	77	7,7	—	—	69	6,9	114	11,4
	July		81	8,1	—	—	—	—	—	—	—	—
	August		—	—	72	7,2	—	—	—	—	—	—

*Correction of orbit.

ID and MD refer to integral and mean daily dose, respectively.

Table 2 lists the results of measurements of integral and mean daily doses aboard Salyut-6 in 5 areas within the station: first and second points in the working compartment, third and fourth in the crew compartment and the fifth in the transfer module.

Analysis of the results revealed that the mean daily doses were related to the location of a dosimeter aboard the station. This could be due to two factors: differences in shielding by elements of the station of the measurement point and contribution to the dosage of radiation belt protons in the area of the South Atlantic anomaly. However, in view of the long period, for which data were averaged (4-10 days, with 90-min access time [cycle]), the influence of the South Atlantic anomaly would be the same for all measurement points, so that the difference is attributable mainly to the first factor.

By the end of the mission of the second expedition in Salyut-6, there was an overt tendency toward decline of mean daily dose at all points measured, which was related to decrease in GCR dose during the period of increased solar activity. As is evident from the data in [4], solar activity increased toward the end of 1978 and remained considerable during 1979-1980. At the same time, the last readings taken in September 1978 at the least shielded point 5 and readings taken 5 days later at the best shielded point, 2, showed that the mean daily dosage was exceeded by 1.5 times. The periods of these readings coincided with a period (point 5) of worsening of radiation conditions due to development of a solar flare on 23 September 1978 and period (point 2) of the start of development of a flare.
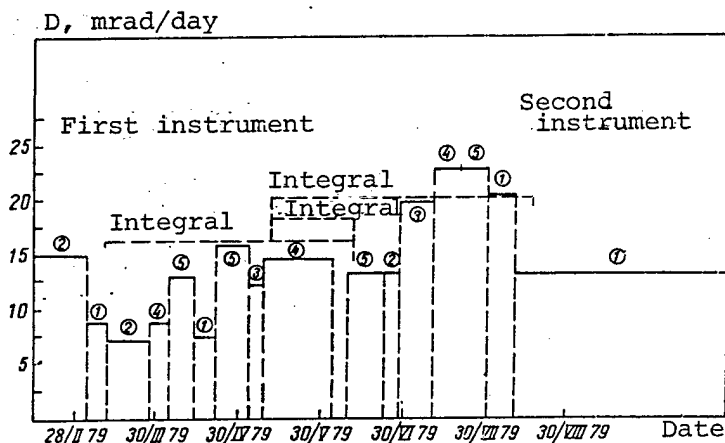
Results of measurements of mean daily doses aboard Salyut-6 using PPD-2 direct-reading dosimeter and "Integral" unit (third mission)

The numerals referal to location of PPD-2 dosimeter:
1, 2) working compartment
3, 4) crew compartment
5) transfer module

Dotted line shows "Integral" assembly

The results of taking measurements in 1979 during work of the third mission were indicative of calm radiation conditions within the station. By April 1979, the mean daily dose decreased to two-thirds—one-half, as compared to 1978, and this was related to decreased GCR flux, in particular, the share of the low-energy component due to modulation effects of intensification of solar activity. At the same time, the distribution of mean daily doses in station modules became more uniform. However, a series of corrections of orbit, namely, increasing altitude to 420 km, led to about 2-fold increase in mean daily dose (doses are listed in Table 2) in all station compartments. Evidently, this was related to the increased contribution of the radiation belt at these altitudes to the mean daily dosage.

The results obtained with the PPD-2 direct-reading dosimeter conform well to data (see Figure) obtained from the international "Integral" experiment during work of the third expedition. This information was characterized by a decline to five-sevenths to two-thirds in mean value of density flux of particle

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ionization in both the intermediate and working module (comparative measurements were made at the start and end of the third mission), which was attributable to modulation effects as a result of increased solar activity.

The radiation conditions were also calm during the fourth mission. The mean daily dose measured with a PPD-2 direct-reading dosimeter constituted 6 to 13 mrad at all points.

In conclusion, it must be noted that the dosimetric features of the PPD-2 research instrument made it possible to use it to assess the radiation conditions during the international "Cytos" experiment aboard Salyut-6. The mean daily doses during this experiment constituted 12 and 15 mrad.

Thus, the studies pursued aboard Salyut-6 station with use of the PPD-2 direct-reading dosimeter revealed that there were considerable differences in levels of mean daily doses, due to shielding by station construction materials. This is indicative of the need to evaluate the shielding in areas of the station where cosmonauts spend the most time. Our findings also were indicative of the desirability of using direct-reading dosimeters aboard MSC for purposes of both individual dosimetric monitoring and monitoring radiation within compartments of spacecraft.

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METHODS

IDENTIFICATION OF HEAVY NUCLEI IN RADIOBIOLOGICAL EXPERIMENTS IN SPACE

[Article by A. A. Marennyy]

[Text] Proper consideration of the contribution of heavy nuclei plays an im-
portant part in assessing and forecasting the radiation hazard of cosmic rays
[1], and for this one needs detailed information about the distinctions of
the effects of these particles on biological systems, together with other
spaceflight factors, as well as more precise data on flux and charge-energy
spectra of heavy nuclei in specific orbits. In such studies, extensive use
is made of dielectric track detectors (DTD) [2-9]. This is attributable to
several of their qualities, the main ones being high charge and spatial
resolution, selective registration of heavy nuclei against a background of
protons and α-particles.

The methods of identifying particles, which most authors use, are based on the
following, essentially similar criteria [3]: the particle is recorded in a
detector if the primary ionization it effects through interaction with the
detector material is not less than the threshold for a given detector; the
particle is recorded in the detector if limited linear energy transfer
(LET_{350} or LET_{1000}) of the particle is not below the threshold for a given
detector upon interaction with detector material.

Threshold values are determined by both the detector material and chemical
treatment after exposure. The methods of determining particle charge in poly-
mer detectors are based on the estimated phenomenological dependence of
lengths of cones of exposure along the trajectoris of particles with a given
charge in successively situated layers of detectors from the same unit on
residual particle range. This function is plotted on the basis of the
experimentally established relationship between rate of exposure of detector
material along the track and primary ionization or LET obtained by estimation
with a given residual range. The identification procedure amounts to measure-
ment of a certain quantity of exposure cone lengths along the trajectory of
the particle and corresponding residual range, then selection of the estimated
curve, on which the aggregate of measured values is plotted in the best way.

The following restrictions are contained in the very essence of these methods:
only nuclei with known residual range can be identified, i.e., those that

stop within the detector; accuracy of identification diminishes with increase in nucleus charge with equal accuracy of baseline readings; to identify nuclei over a wide range of charges with the same absolute margin of error, one must increase the quantity of cone lengths measured along a track for particles with greater charge; accuracy of measurements of cone lengths must constitute 1-2 μm, which is the reason they are time-consuming; the material of which the detector is made must be highly homogeneous on both the surface and in depth.

Track length is used to identify particles according to charge in crystal DTD [3]. We shall validate here an analogous method for identification of polymer DTD, and results of developing it for cellulose nitrate are submitted. This method is partially free of the above-mentioned restrictions.

Let there be a rather thick detector unit exposed to a flux of heavy nuclei. After disassembling the unit and exposing detectors, exposure cones will appear along the trajectories of the particles (track segments, Figure 1).
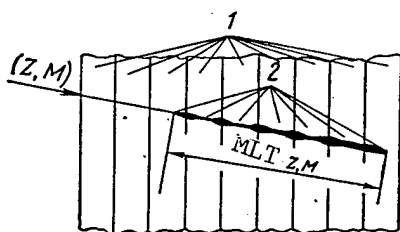

Figure 1.
Diagram of track in DTD unit
1) detectors
2) track segments
Arrowhead along trajectory shows direction of particle flight.

The first track segments will appear in the direction of flight of particles in points where velocity diminishes to a level that is sufficient for the limited linear energy transfers LET_ω to exceed the threshold for a given detector and the mode of exposure $LET_{\omega,0}$. The last track segment along the trajectory will be virtually at the point where the particle stops. Since the value of LET_ω is determined, aside from velocity, by charge and mass of the particle, it is apparent that the total length of the trajectory (or maximum length of track--MLT) over which $LET_\omega \geqslant LET_{\omega,0}$ is a one-to-one function of particle characteristics.

Let us examine MLT as a function of charge Z and mass M of the particle. Assuming that one of the particles is a proton in the known correlation between lengths of tracks of different particles with the same energy per nucleon [10], we shall obtain:

$$R_{Z,M} = \frac{M}{Z^2} R_p, \tag{1}$$

where R_p is proton path, $R_{Z,M}$ is path of particle with charge Z and mass M.

In the range of mean energies, the proton path is approximated as an exponential function of its energy E:

$$R_p = a \cdot \dot{E}^b, \tag{2}$$

where a and b are parameters that depend on the medium and energy range.

Substituting equation (2) in (1), we shall have:

$$R_{Z,M} = a \cdot \frac{M}{Z^2} \cdot E^b. \qquad (3)$$

The last equation yields a value of $R_{Z,M,max}$ = MLT, if in the right part E equals maximum energy E_{thr} [thr--threshold], at which a track is formed. The equation for E_{max} is derived from the formula of Bethe-Block for LET_ω [10], if in the left part we replace size as a function of particle velocity with its function of energy (in megaelectron volts per nucleon) and assume that [or write down] E = E_{thr}, and in the right part $LET_{\omega,0}$. Then, omitting the intermediate calculations, we shall finally have:

$$R_{Z,M,max} = aK \left(\frac{n}{LET_{\omega,0}} \right)^b MZ^{2\,(b-1)}, \qquad (4)$$

where K is a coefficient that contains the fundamental constant from the formula of Bethe-Block and n is electron density of ambient [medium] material.
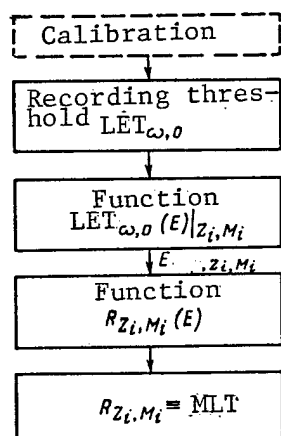

Figure 2.
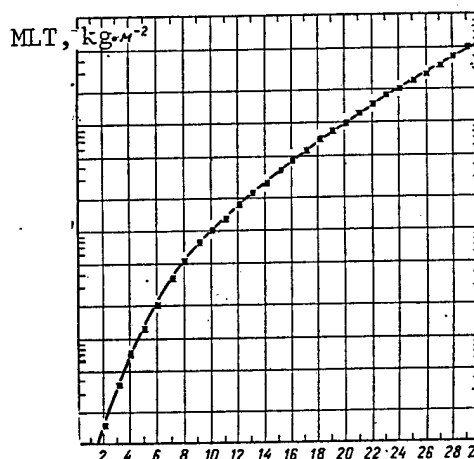Flowchart for MLT estimates

Figure 3.
MLT as a function of nucleus charge Z in cellulose nitrate

According to equation (4), maximum exposed length of MLT is a function of particle charge and, consequently, is a reliable identification criterion. Let us also note that, with a given charge Z of the particle, MLT is proportional to mass M which, in principle, permits identification of isotopes.

The submitted calculations are approximate, and they can be interpreted merely as validation of the method. MLT as a function of particle charge and mass can actually be obtained by estimation, based on measured threshold of recording $LET_{\omega,0}$ for a given detector material at the selected conditions of exposure and measurement of tracks. For cellulose nitrate, calculations were made using the flowchart illustrated in Figure 2. The value of threshold of recording LET_{1000} = 200 KeV/μm was obtained from the results of calibrating irradiation of material samples with ions of helium, boron, carbon with energy of 2-10 MeV/nucleon and ions of argon (~200 MeV/nucleon) and iron (~500 MeV/ nucleon). Exposure of cellulose nitrate was performed in 6 N aqueous NaOH solution at 313°K. The required data on path-energy ratios and LET were taken from [11].

Figure 3 illustrates MLT as a function of particle charge for the most widespread isotopes. The error of the submitted data, which is determined by the error of measurement of recording threshold and accuracy of estimation data used constitutes ~4%. Processing of the entire array of obtained values for $R_{Z,M,max}$ enabled us to have the following equations:

$$R_{Z,M,max} = \begin{cases} 4,73 \cdot 10^{-5} M Z^{2,0}, & 2 \leqslant Z \leqslant 12 \\ 9,30 \cdot 10^{-6} M Z^{2,65}, & 13 \leqslant Z \leqslant 30 \end{cases} \qquad (5)$$

Considering that $M \simeq 2Z$ for all of the most widespread isotopes of nuclei with charge $2 \leqslant Z \leqslant 12$ and $M \simeq 2.36 Z$ in the range of $13 \leqslant Z \leqslant 30$, and substituting these functions in (5), we shall have:

$$R_{Z,max} = \begin{cases} 9,5 \cdot 10^{-5} Z^{3,0}, & 2 \leqslant Z \leqslant 12 \\ 2,2 \cdot 10^{-5} Z^{3,7}, & 13 \leqslant Z \leqslant 30 \end{cases} \qquad (6)$$

A conclusion of practical importance can be drawn from the last equations. Let there be 2 particles, the charges of which are greater than 13 and which differ by 1 from one another. Then, according to (6), it follows that:

$$R_{Z+1,max} - R_{Z,max} = 8 \cdot 10^{-5} Z^{2,7}, \qquad (7)$$

i.e., the permissible margin of error in measurement of MLT, with which adjacent charges are allowed can be all the greater, the higher the charge of the particles (or MLT).

Equation (6) also enables us to assess the charge resolution of the method with use of the detectors in question. Indeed, after differentiation and the obvious conversions, we have:

$$\frac{\Delta Z}{Z} = \begin{cases} 0,33 \Delta R_{Z,max} / R_{Z,max}, & 2 \leqslant Z \leqslant 12 \\ 0,27 \Delta R_{Z,max} / R_{Z,max}, & 13 \leqslant Z \leqslant 30 \end{cases} \qquad (8)$$

As can be seen in (8), with equal relative error $R_{Z,max}$ the accuracy of identification in the charge ranges considered is about the same. $\Delta R_{Z,max}$ contains error of calculation $R_{Z,max}$ and several errors that arise in measuring track lengths. Assuming that experimental errors equal zero and estimated ones 4%, we shall obtain an essentially possible resolution: $\Delta Z / Z = 1-2\%$ in cellulose nitrate.

In actual measurements, relative error $\Delta R_{Z,M,max} / R_{Z,M,max}$ does not remain constant over the entire range of change in values. For this reason, let us consider charge resolution as a function of absolute error $\Delta R_{Z,M,max}$. Substituting (6) in (8), we shall have:

$$\frac{\Delta Z}{Z} = \begin{cases} 3,5 \cdot 10^3 \Delta R_{Z,max} Z^{-3,0}, & 2 \leqslant Z \leqslant 12 \\ 1,2 \cdot 10^4 \Delta R_{Z,max} Z^{-3,7}, & 13 \leqslant Z \leqslant 30 \end{cases} \qquad (9)$$

hence, with equal absolute margin of error for $R_{Z,max}$, the relative accuracy of identification increases with increase in particle charge. As for absolute error of determining charge, it is apparent from equations (10) and (12) [not furnished in source] that with increase in charge of particles it increases when there is equal relative error and decreases with equal absolute error of $R_{Z,max}$.

In order to determine nuclear charge and mass by the described method, one must know the full length of the track (MLT), which equals the sum of lengths of track segments in successively arranged detecting layers. The measurement procedure is described in greater detail in [12]. Measurement of MLT takes less time and is less labor-consuming than measurement of cone lengths, particularly if the multilayer scanning method is used [12].

Identification of heavy nuclei of cosmic radiation according to charge with the above-described method revealed that a margin of error of 0.5-0.3 charge units in the range of charges exceeding 22 is achieved when measuring tracks with a rather large error--300-400 µm. Similar accuracy is obtained with use the identification method for velocity of exposure ["priming"] along the track from measurement of length of 9-20 cones with a margin of error of 1-2 µm [13].

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BRIEF REPORTS

SEROTONIN CONCENTRATION IN ISOLATED NUCLEI OF THE HYPOTHALAMUS, LIMBIC SYSTEM
AND BRAIN OF RATS FOLLOWING FLIGHT ABOARD COSMOS-1129 BIOSATELLITE

[Article by J. Chulman, R. Kwetniansky and R. A. Tigranyan]

[Text] This work deals with investigation of serotonin (5-hydroxytryptamine)
in isolated nuclei of the rat hypothalamus, limbic system, brain stem and
cerebellum after a long-term spaceflight aboard Cosmos-1129 biosatellite. It
should be noted that serotonin content of the animal brain after spaceflight
had not yet been investigated.

Methods

We conducted the studies on male Wistar-SPF (Bratislava, CSSR) rats, flown
aboard Cosmos-1129 in space for 18.5 days. The animals were sacrificed
6-8 h after landing and on the 6th postflight day. Some of the animals
sacrificed on the 6th postflight day had been submitted to immobilization
stress 5 times (150 min daily); control and synchronous groups of rats were
also submitted repeatedly to immobilization stress.

Sections 300 μm in thickness were prepared from the rat brain, which
had been frozen in a cryostat at a temperature of -15°C; the nuclei were iso-
lated from the sections under a microscope by the method in [1]. The recov-
ered tissue was homogenized in 60 μl 0.1 N $HClO_4$; 15 μl homogenate was used
to assay protein concentration [2], and the rest was centrifuged under refri-
geration at 10,000 G. We used 10 μl supernatant to assay serotonin. Serotonin
was assayed by a highly sensitive radioenzymatic micromethod [3]. Statistical
reliability was calculated using Student's t test.

Results and Discussion

We demonstrated relatively minor changes in animals sacrificed immediately
after landing in concentration of serotonin in nuclei of the hypothalamus; sero-
tonin level was low in the periventricular nucleus, as compared to the vivarium
control, whereas in the paraventricular nucleus, on the contrary, it was higher
than in the synchronous experiment (Table 1). We failed to demonstrate changes
in concentration of serotonin in limbic system and brain stem nuclei (Tables 2
and 3); there was a reliable increase in concentration of serotonin in the
cerebellar cortex of flight and synchronous groups of rats, as compared to
the vivarium control (Table 4).

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Table 1. Serotonin content in hypothalamic nuclei (M±m, ng/mg protein)

Group		Time of assay	nucleus supra-chiasmaticus	nucleus periven-tricularis	nucleus supraop-ticus	nucleus ventro-medialis
1	V	After 6-8 h	15,62±2,32	16,44±1,55	10,90±1,02	13,83±2,33
	F	(n=7)	15,01±1,71	10,90±1,57	15,09±2,00	13,09±2,30
	S		12,58±2,02	17,29±2,72	14,39±2,74	13,19±2,35
2	V	After 6 days	8,87±0,78	9,48±1,17	11,03±2,12	7,91±1,69
	F	(n=6)	8,16±1,17	6,95±0,79	8,80±1,39	9,09±1,23
	S		8,78±1,42	9,23±2,66	11,65±2,29	7,72±0,88
3	V	After 6 days	9,47±1,31	8,93±0,96	10,24±0,87	12,28±1,55
	F	+immobiliza-	9,81±1,18	9,41±1,02	13,23±0,76	11,39±1,26
	S	tion (n=7)	11,04±1,17	8,18±1,01	13,41±1,36	13,79±0,89
Reliability				$V_1:F_1$ $p<0,05$	$F_2:F_3$ $p<0,01$	$S_3:S_2$ $p<0,001$

Group		Time of assay	nucleus paraven-tricularis	eminentia me-dialis	nucleus arcuatus	nucleus dorsome-dialis
1	V	After 6-8 h	12,17±1,32	24,85±1,53	15,28±1,43	20,74±2,72
	F	(n=7)	16,80±3,87	18,29±4,23	10,69±2,30	14,93±2,80
	S		18,30±2,32	20,63±3,40	16,55±2,20	18,75±2,21
2	V	After 6 days	13,11±1,35	18,07±3,47	11,54±2,65	8,01±1,36
	F	(n=6)	10,94±8,37	17,17±3,32	11,41±1,05	8,67±9,79
	S		17,62±3,52	17,38±3,03	11,00±1,43	8,92±0,90
3	V	After 6 days	14,19±1,09	27,11±2,66	18,61±1,93	16,73±1,59
	F	+immobiliza-	17,70±1,48	16,91±3,00	15,01±2,99	16,42±1,64
	S	tion (n=7)	15,51±0,74	20,93±3,91	16,53±3,24	17,34±3,57
Reliability			$U_1:S_1$ $p<0,05$		$S_2:S_3$ $F_2:F_3$ $V_2:V_3$	$p<0,001$ $p<0,01$ $p<0,01$

Note: Here and in Tables 2-4: V--vivarium control, F--flight, S--synchronous experiment.

Six days after the flight, there were no demonstrable changes in serotonin concentration in nuclei of the hypothalamus, cerebellum, brain stem and limbic system of the rats, with the exception of a reliable decline in the nucleus raphe magnus in flight and synchronous groups of animals, as compared to the vivarium control (see Table 3).

However, when the rats were submitted to repeated immobilization after landing, an increase was demonstrated in serotonin concentration in the supraoptical and dorsomedial nuclei of flight animals, as compared to analogous nonimmobilized rats. Elevation of serotonin level in the dorsomedial nucleus was also found in both control groups, and in the ventromedial nucleus only in rats in the synchronous control, as compared to nonimmobilized animals of analogous groups (see Table 1). We found no changes in serotonin concentration in limbic system nuclei (see Table 2). An elevation of serotonin level after repeated immobilization was demonstrated in region A_1 of the brain stem of rats in the flight group, as compared to analogous animals who were not immobilized. In region A_2

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of the brain stem, serotonin concentration was low in animals submitted to repeated immobilization that had flown in space, as compared to immobilized vivarium control animals (see Table 3).

Table 2. Serotonin content of the limbic system (M±m, ng/mg protein)

Group	Time of assay	nucleus amygdaloideus centralis	nucleus amygdaloideus lateralis	Septum
1 V	After 6–8 h	13,35±2,32	16,95±1,32	5,47±0,41
F	(n=7)	10,04±4,73	11,89±2,89	5,58±0,81
S		12,22±1,14	12,50±1,96	5,89±0,40
2 V	After 6 days (n=6)	9,25±0,36	11,09±1,79	4,61±0,61
F		7,72±1,00	9,3±1,90	4,24±0,43
S		7,52±0,48	10,40±1,06	4,37±0,48
3 V	After 6 days + immo-	7,73±0,74	12,30±2,00	4,84±0,83
F	bilization (n=7)	9,38±0,68	10,23±1,30	3,40±0,87
S		7,39±0,77	12,33±1,13	4,15±0,35

Table 3. Serotonin content of the brain stem (M±m, ng/mg protein)

Group	Time of assay	A_1	A_2	locus ceruleus	nucleus raphe magnus
1 V	After 6–8 h (n=7)	15,61±1,99	16,93±4,37	15,56±1,51	15,42±1,94
F		10,73±1,61	18,44±2,51	18,25±1,07	15,52±0,83
S		13,14±1,74	15,70±1,51	18,20±2,00	16,22±1,96
2 V	After 6 days (n=6)	21,66±4,51	23,78±2,84	29,93±2,82	24,33±0,83
F		17,74±2,32	24,26±3,77	21,67±3,55	17,87±2,25
S		16,72±2,08	22,38±2,72	26,03±3,38	16,61±1,95
3 V	After 6 days +	24,57±3,16	26,41±2,27	26,18±3,30	27,50±2,01
F	immobilization	26,87±2,66	20,30±1,10	28,67±2,81	24,29±3,16
S	(n=7)	18,26±3,75	23,10±2,59	27,02±3,56	20,77±3,56
Reliability		$F_2{:}F_3$ $P<0,05$	$V_3{:}F_3$ $P<0,05$		$V_2{:}F_2$ $P<0,05$ $V_2{:}S_2$ $P<0,01$

At the present time, there is very little information about the effect of stress on serotonin concentration in isolated nuclei of the brain. After immobilization stress a decline [4] and, on the contrary, elevation of serotonin level have been reported in some nuclei of the brain. From the standpoint of regulation of neuroendocrine reactions, the hypothalamic region is very important. We failed to detect noticeable changes in serotonin concentration in hypothalamic nuclei.

There is no information in the literature concerning changes in serotonin concentration in rats submitted to repeated immobilization. From this point of

Table 4.
Serotonin content of cerebellum (M±m, ng/mg protein)

Group	Time of assay	Serotonin content
1 V F S	After 6-8 h (n=7)	$3,02\pm0,18$ $4,03\pm0,35$ $4,83\pm0,44$
2 V F S	After 6 days (n=7)	$4,69\pm0,43$ $5,06\pm0,45$ $5,10\pm0,27$
3 V F S	After 6 days + immobilization (n=7)	$5,85\pm0,78$ $4,58\pm0,55$ $5,72\pm1,08$
Relia- bility	$V_1:F_1$ $P<0,05$ $V_1:S_1$ $P<0,01$	

view, the elevation of serotonin level in the dorsomedial and supraoptical nuclei of flight rats submitted to repeated immobilization is of interest; we observed such a reaction to repeated stress in the dorsomedial nucleus of vivarium control rats and in the ventricular nucleus of animals in the synchronous experiment. We observed increase in serotonin concentration in the ventricular and dorsomedial nuclei in our experiments in rats submitted to immobilization 6 times (150 min daily).

The limbic system also plays a significant modulating role in regulation of neuroendocrine reactions. However, the concentration of serotonin in the examined limbic system nuclei did not change under the effect of the spaceflight or subsequent repeated immobilization stress. These findings may indicate that very probably the serotonin of the limbic system is not a very important factor in regulating autonomic functions that are activated under stress.

Perikaryons of aminoergic neurons are situated mainly in the lower part of the brain stem. To date, there are no data in the literature about the effect of stress on concentration in the nucleus raphe magnus, locus ceruleus, regions A_1 and A_2. In our studies, no changes were demonstrated in serotonin concentration in any of the listed regions of the brain stem under the effect of acute and repeated immobilization stress. In view of the fact that perikaryons of serotoninergic neurons are situated in the nucleus raphe magnus, the drop of serotonin level in this nucleus on the 6th postexperimental day in rats from the flight and synchronous groups, as compared to the vivarium control, is interesting. The data referable to increased concentration of serotonin in the cerebellar cortex of rats in the flight and synchronous groups immediately after the experiment are also remarkable.

In conclusion, it should be noted that the greatest changes in serotonin concentration were observed in some hypothalamic nuclei of flight group rats submitted to repeated immobilization after the flight. It appears that reactivity of the hypothalamic serotoninergic system of these animals was altered; this could be significant to regulation of various autonomic functions.

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GAZE FIXATION USED TO SUPPRESS VESTIBULAR NYSTAGMUS

[Article by G. I. Gorgiladze, S. P. Ritter, V. N. Sarychev and V. N. Sablin]

[Text] High-speed aviation and cosmonautics create adverse conditions for normal function of the vestibular system. The reactions that occur could lower appreciably the work capacity of pilots and cosmonauts.

In our opinion, regulation of vestibular reactions by other sensory systems, in particular vision, is a means of eliminating or alleviating undesirable vestibular reactions. According to the reports of some Soviet cosmonauts, the vertigo and spatial illusions that occur in weightlessness become more marked when the eyes are closed [1].

We report here on a study and quantitative evaluation of the role of fixation in suppressing vestibular nystagmus.

Methods

The study was conducted with 30 subjects, males and females, 18 to 24 years of age. A group of 20 subjects consisted of sportsmen, whose main element of athletic training is fixation of a target (master candidates and master marksmen).

The control group consisted of 10 subjects who had no such sports training. All of the subjects were essentially healthy, had normal vision and no history of ear, nose and throat diseases. They were submitted to clockwise rotation in seated position, with the head bent 30° forward to stimulate the horizontal semicircular canals. They were rotated at a positive angular acceleration of $15°/s^2$ to a velocity of 90, 120, 180 and 210°/s. Rotation at a constant speed lasted 1 min. This was followed by negative acceleration for 0.15-0.30 s. (stop stimuli). The subjects were rotated on this schedule twice at 5-min intervals: with gaze fixation and in the dark. In the former case, the subjects were instructed to fix their gaze on a light spot, a point source of light, placed 1.5 m from the subject on a footrest. In the latter case, the subjects wore opaque [lightproof] goggles with their eyes open during rotation. The electronystagmogram was recorded by means of silver cup electrodes, 5 mm

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in diameter, placed over the lateral canthi and registered on a nystagmograph, with time constant of 1.5 s, throughout the period of rotation and aftereffect. We used the "fixation index" [2]--relative number of nystagmic jerks and duration of reaction in the dark and with gaze fixation--to assess the effect of fixation on vestibular nystagmus.

Results and Discussion

The Table lists the results of testing the subjects' vestibulo-oculomotor reaction with fixation and in the dark.

Parameters of nystagmic reaction of marksmen (top figures) and control group (bottom) to positive angular accelerations of 15°/s² and negative accelerations with gaze fixation and in the dark (M±m)

Parameter of nystagmus	Rate of rotation, °/s							
	90		120		180		210	
	F	D	F	D	F	D	F	D
Positive accelerations								
Number of jerks	0	67.6±8.1	2.3	72.0±8.9	7.0±1.2	78.2±9.7	10.0±2.1	86.0±13.1
	0	63.0±9.9	12.0	67.8±10.1	32.0±3.7	81.0±11.8	38.0±4.3	83.1±15.3
Duration of reaction, s	0	37.1±3.4	1.4	35.3±4.1	3.7±0.7	37.0±3.9	6.0±1.1	39.3±4.5
	0	32.0±2.9	4.0	33.9±5.5	16.3±2.1	38.9±6.7	18.3±2.7	37.0±7.1
Negative accelerations								
Number of jerks	0	57.5±7.0	5.0±0.8	70.6±9.3	15.0±3.9	82.0±9.1	25.3±4.1	81.0±8.3
	12.3±2.3	51.0±5.8	24.6±3.8	75.1±11.6	41.0±5.7	85.4±13.3	51.6±8.0	78.7±7.3
Duration of reaction, s	0	31.2±3.8	3.3±0.3	35.8±3.5	6.6±1.1	39.7±4.1	12.4±2.2	37.6±4.1
	7.0±1.9	35.3±4.9	13.2±2.7	36.0±7.1	24.5±3.1	40.1±5.8	32.0±4.8	33.7±6.0

Key: F) gaze fixation   D) darkness

With positive angular acceleration of 15°/s to a rotating velocity of 90°/s, all subjects showed no nystagmic eye movements during gaze fixation. With acceleration to 120°/s, nystagmus was demonstrated in only 3 marksmen and half the subjects in the control group. With acceleration to 180 and 210°/s, nystagmus was observed in 7 and 9 tested marksmen and all subjects of the control group. With a stop stimulus of 90°/s and gaze fixation, the marksmen presented no nystagmus, while it was demonstrated in 9 out of the 10 control subjects. With stop stimuli of 120, 180 and 210°/s, this parameter was noted in 14, 16 and 18 marksmen, respectively, and in all subjects of the control group.

The data in the Table show that, with gaze fixation, the nystagmic reaction was reliably different in marksmen with all stimuli used, according to number of nystagmic jerks and duration, from that of the control group. At the same time, virtually identical nystagmic reactions were demonstrated in both groups of subjects when tested in the dark (see Table and Figure 1).

Determination of fixation indexes for marksmen yielded the following figures: 31.3 according to number of jerks and 25.2 for reaction time with acceleration to 120°/s. With acceleration to 180°/s, the fixation index constituted a mean of 11.2 and 10.0, respectively, and with acceleration to 210°/s, 8.6 and 6.5. In the control group of subjects, the fixation indexes were considerably

lower: with acceleration to 120°/s, average of 5.6 for the number of jerks and 8.5 for reaction time, and with acceleration to 180 and 210°/s, 2.5 and 2.4, 2.2 and 2.0, respectively. Figure 2 graphically illustrates the fixation indexes with use of negative accelerations on both groups of subjects. As can be seen in this figure, the fixation indexes for marksmen with a stop stimulus of 90°/s were infinitely high, and with the other stop stimuli they were several times higher than in the control group of subjects.
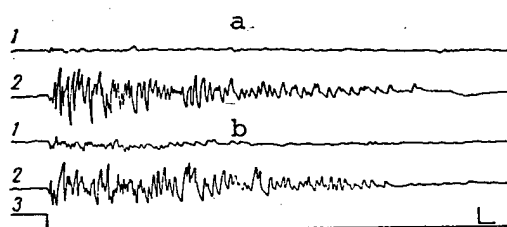

Figure 1.

Nystagmic reaction of marksman (a) and untrained subject (b) to stop stimuli at angular velocity of clockwise rotation of 180°/s with fixation (1) and in the dark (2)

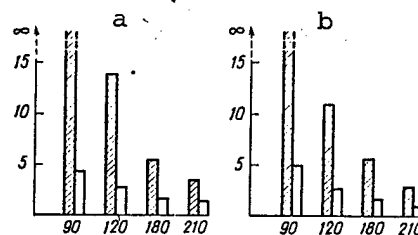3) stop stimulus mark

Calibration: 10°, 2 s

Figure 2.

Graphic depiction of fixation indexes for overall number of nystagmic jerks (a) and duration of reaction (b) in marksmen (crosshatched columns) and untrained subjects (white columns) in response to stop stimuli at angular rotation velocities of 90, 120, 180 and 210°/s

As a result of these studies, we demonstrated distinct suppression of the vestibulo-oculomotor reaction to stimuli of increasing intensity in the case of gaze fixation. And, the stronger the stimulus, the less marked was this phenomenon. It was previously shown that there is a rise of thresholds of appearance of nystagmus in response to angular accelerations and suppression of caloric nystagmus with gaze fixation [3, 4]. Apparently, the phenomenon of visual suppression of vestibular reactions is attributable primarily to congenital mechanisms of optovestibular interaction. At the same time, the fixation indexes were several times higher for marksmen than untrained subjects. Thus, training fixation capacities of the eye leads to significant increase in inhibitory effect of fixation on the vestibular system. Our results indicate that it is probably expedient to combine vestibular conditioning with special training of the visual system, aimed at improving eye fixation ability, in order to enhance vestibular stability of man.

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QUANTITATIVE EVALUATION OF EFFECTS OF PHYSICOCHEMICAL AND TECHNOLOGICAL
FACTORS ON WATER REGENERATION PROCESS

[Article by N. M. Krivobok, V. B. Gaydadymov, V. V. Nosov and G. G. Ter-Minas'yan]

[Text] The creation of space life-support systems that operate for a long
period of time implies development of new technological processes for regenerat-
ing water from various water-containing products and waste formed right on
board a manned space vehicle, as well as constant refinement of existing pro-
cesses [1]. Ground-based testing of equipment that is being developed, with
regard to its different parameters, is an important element of such research.
The effectiveness of experimental research could be improved substantially by
studying the methodology of mathematical experiment planning, which permits
obtaining the necessary information with minimum expenditure of time and
resources.

Our objective here was to determine the quantitative evaluations of effects
of a number of physicochemical and technological factors on the process of
removal of component A from fluid in an electrolyzer, with use of the methodo-
logy of orthogonal planning of the experiment.

Methods

We used a unit, the simplified flowchart of which is illustrated in the Figure,
for our studies. Original fluid was passed from delivery unit 1 into electro-
lyzer 2, which contained solid electrolyte in the form of an ion-exchange
diaphragm and a charging ["feed"] electrode, in which removal of component A
dissolved in this fluid was effected. The fluid treated in electrolyzer 2 was
passed into tank 3. Sensor 4 was installed at the outlet of electrolyzer 2,
which indicated the degree of purification of the initial fluid. Adjustable
voltage stabilizer 5 served to supply power to electrolyzer 2.

We selected for our experiment the following factors, the degree of effects of
which on output characteristics of the process we were to evaluate: X_1--debit
of treated fluid (in ℓ/s), X_2--voltage to electrolyzer (in V), X_3--concentra-
tion of component A in the fluid (in mg/ℓ), X_4--concentration of electrolyte
in the fluid (in mg/ℓ), X_5--factor simulating the effect of gravity (dimension-
less), X_6--concentration of catalyst on charging electrode of the electrolyzer
(%) and X_7--thickness of charging electrode (mm).

Table 1.
Matrix for planning and results of experiment to study process of liquid purification in electrolyzer

Test No	x_1	x_2	x_3	x_4	x_5	x_6	x_7	$\bar{y}_1$	$\bar{y}_2$
1	−1	+1	−1	−1	−1	+1	+1	85	100
2	+1	−1	−1	−1	+1	+1	−1	55	100
3	−1	−1	−1	+1	+1	−1	+1	25	96
4	−1	−1	+1	+1	−1	+1	−1	65	100
5	−1	+1	+1	−1	+1	−1	−1	68	87
6	+1	+1	−1	+1	−1	−1	−1	53	93
7	+1	−1	+1	−1	−1	−1	+1	30	23
8	+1	+1	+1	+1	+1	+1	+1	70	84

We took six parameters as output indicators characterizing the effectiveness of the liquid treatment process in the electrolyzer, two of which are of the greatest interest: Y_1--angle of inclination of the curve of distribution of polarization potentials of the treatment electrode on the flowing axis of the treated fluid (in degrees) and Y_2--degree of purification of fluid in electrolyzer (%).

For quantitative evaluation of the effects of the selected factors on the above-mentioned characteristics of the liquid treatment process to remove component A, we selected the orthogonal plan of Plakett-Berman [2], the matrix of which is shown in Table 1. The coding for levels of factors is listed in Table 2. The degree of influence $\hat{a}_i^{(k)}$ of factor X_i ($i = 1.7$) on output parameter Y^k ($k = 1.2$) was estimated using the following formula [2]:

$$\hat{a}_i^{(k)} = \left(\sum_{s=1}^{N} x_i^{(s)} \bar{Y}_k^{(s)} \right) / N,$$

where x_i^s is the coded value of level of factor X_i in the sth experiment ($s = \overline{1, N}$), $\bar{Y}_k^s$ is mean value of output parameter Y^k ($k = \overline{1.2}$) in the sth test and N is the number of tests in the plan matrix.

Table 2. Conditions for coding factor levels

| Factors	Bottom level ($x_i = -1$)	Top level ($x_i = +1$)
X_1	0.25 ℓ/s	0.75 ℓ/s
X_2	0.8 V	1.4 V
X_3	3.4 mg/ℓ	10 mg/ℓ
X_4	5 mg/ℓ	200 mg/ℓ
X_5	Horizontal position of electrolyzer electrode	Vertical electrode posit.
X_6	2.5%	5%
X_7	1.85 mm	3.3 mm

Results and Discussion

Table 1 lists the results of measurements obtained with use of the Plakett-Berman plan, while the calculations using the above formula are listed in Table 3.

Since estimates of measurement errors for output parameters of the process under study constitute 5-10%, Table 3 lists only the values of $\hat{a}_i^k$ the absolute levels

Table 3.
Quantitative estimates of effects of tested factors on output parameters of liquid treatment process in electrolyzer

$\bar{Y}^k$	$\hat{a}^{(k)}$	$\hat{a}_2^{(k)}$	$\hat{a}_3^{(k)}$	$\hat{a}_4^{(k)}$	$\hat{a}_5^{(k)}$	$\hat{a}_6^{(k)}$	$\hat{a}_7^{(k)}$	$\hat{a}_0^{(k)}$
$\bar{Y}_1$	$-4{,}4$	$+12{,}6$	—	$-3{,}1$	—	$+12{,}4$	$-3{,}9$	$56{,}4$
$\bar{Y}_2$	$-10{,}6$	—	$+11{,}8$	—	—	$+10{,}6$	$-9{,}6$	$85{,}4$

Note: $\hat{a}_0^{(k)}$ is defined as the mean value of parameter $\bar{Y}_k$ ($k = \overline{1.2}$) for all (N) tests.
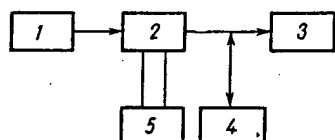
Flowchart of unit for studying liquid treatment process in electrolyzer

of which exceed the error of measurement of corresponding mean values $\hat{a}_0^{(k)}$ of output parameters.

Analysis of the signs of calculated values of $\hat{a}_i^{(k)}$ enables us to determine the nature of effect of each factor X_i ($i = \overline{1.7}$) on output parameter Y_k ($k = 1.2$). For example, with increase in value of factor X_1 output parameters Y_1 and Y_2 decrease and, conversely, an increase in value of X_6 leads to increase in value of output parameters.

Table 3 shows that the degree of effect of the factors tested on output parameters Y_1 and Y_2 is dissimilar in the general case (absolute values of $\hat{a}_i^{(k)}$ are different). Thus, for output parameter Y_1, the following factors are the most relevant: voltage X_2, concentration of catalyst X_6, debit of treated fluid X_1 and thickness of charging electrode X_7. At the same time, the effect of chemical composition of the liquid on parameter Y_1 was insignificant (absolute values of $\hat{a}_3^{(1)}$ and $\hat{a}_4^{(1)}$ are low) within the range of selected intervals of variation of factors X_3 and X_4 (see Table 2).

Examination of the quantitative estimates of degree of influence of the tested factors on output parameter Y_2 shows that their absolute values differ insignificantly, i.e., the effect of the most relevant factors X_1, X_3, X_6 and X_7 on parameter Y_2 is virtually the same. The effect of factors X_4 (concentration of electrolyte in the liquid) and X_2 (voltage fed to electrolyzer) could be disregarded, since it did not exceed the margin of error of measurements for parameter Y_2 with change in values of factors X_2 and X_4 within the limits of variation intervals (see Table 2). Consequently, if we take into consideration only parameter Y_2 and proceed from considerations of saving energy, in the future we should select a value for factor X_2 that corresponds to the bottom level.

In conclusion, it should be noted that the effect of factor X_5, which simulates the effect of gravity on output parameters Y_1 and Y_2, was also found to be negligible.

Our results are indicative of a need to continue with such studies. The process in question should be optimized with regard to physicochemical and design-technological factors X_1, X_2, X_3, X_6 and X_7 which, as we have demonstrated above, have the most appreciable effect on output characteristics of this process, keeping the levels of the other factors constant.

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BOOK REVIEWS

NEW BOOK DEALS WITH HISTORY OF SOVIET AVIATION PSYCHOLOGY

[Review by K. K. Ioseliani of book "K istorii otechestvennoy aviatsionnoy psikhologii" [History of Soviet Aviation Psychology] edited by K. K. Platonov, Izdatel'stvo Nauka, Moscow, 1981, 319 pages]

[Text] This book performs an important and noble task, that of shedding light on the heroic past of Russian aviation psychology. This task, which is not easy in itself, is also complicated by the fact that there had not been any basic works published on this subject before.

The last two decades, which are justifiably called the years of the space age, would appear, at first glance, to obscure events of days of the distant past. But this only appears so at first glance. It is expressly in our times that each new triumph of Soviet science and technology intensifies interest in aviation and cosmonautics of the past. Human reason has always tried to disclose the patterns of prior events in order to better understand and evaluate the present, to see the germ of the future and make this future better and happier.

However, researchers who tried to open the curtain of time are faced with a number of extremely difficult problems. Unfortunately, many records (let alone unofficial testimony of witnesses) are virtually inaccessible to the modern reader. Moreover, it is difficult to get one's bearings in the ocean of historical facts, even for a specialist who has access to such information.

To produce the book being reviewed, the compilers used 230 official documents, letters and memoirs of witnesses of inception of Soviet aviation psychology. It would seem that this material, which is dry in form and presented in chronological order, unfolds to the reader the grand panorama of man's quest and daring over a period of more than 130 years, from the first flight in Russian scientific practice, which was made in 1804 by Academician Ya. D. Zakharov, to the events of 1940.

The roads of development of any science are complex and dramatic, and it is difficult to trace them. It is difficult to integrate into a single cloth the variegated kaleidoscope of events and facts, personages and ideas. And this makes it all the more pleasant to see that the compilers of this collection

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succeeded entirely in doing this. The reader is offered a book that is written scientifically, but comprehensible and entertainingly. This manuscript of victories of Soviet science, which does not conceal the difficulties and mistakes, is a sort of reference guide which is readable with great interest.

At the same time, the book is not without some flaws. Thus, for the sake of adhering to "chronological order" (p 11), it would have been desirable to place the letters and recollections of witnesses in the main part of the book, using them to illustrate official documents, rather than in a separate appendix (which is obviously inconvenient to the reader). Moreover, in a book dealing with the history of aviation psychology, more attention should have been given to biographies of "individuals who played a noticeable part in development of aviation psychology" (p 10). These biographies deserve to have been published as separate documents, whereas in the book they are printed in brevier type, in footnotes, and dates of birth and death are not always given.

However, these flaws do not minimize the qualities of the book under review. It will, unquestionably, be welcomed with interest and satisfaction by broad circles of specialists and individuals interested in aviation, psychology and history of the science.

Since the printing is small (3600 copies), it would be desirable to republish it so that it, in turn, would "not become a bibliographic rarity" (p 9), like its sources. It is left for us to express the desire that light would be shed on wartime and postwar periods of development of aviation psychology in the next edition of the book. This would bring us right up to the history of space psychology.

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OBITUARIES

ANDREY VLADIMIROVICH LEBEDINSKIY (1902-1982)

[Article by editorial board]

[Text] This year will mark the 80th anniversary of the birth of Prof Andrey Vladimirovich Lebedinskiy, academician of the USSR Academy of Medical Sciences, Honored Scientist of RSFSR, Major General of the Medical Service, outstanding physiologist, brilliant educator and major organizer of medical science.

Andrey Vladimirovich was born on 12 May 1902 in Leningrad, to the family of the well-known scientist-physicist, Prof V. K. Lebedinskiy.

He graduated from the Military Medical Academy (MMA) in 1924 and served in different institutions of the Red Army. From 1928, A. V. Lebedinskiy worked in the Department of Physiology of the MMA, where he advanced from laboratory technician to deputy head of the department. In 1953, A. V. Lebedinskiy headed the Department of Physiology of the Naval Medical Academy; from 1954 to 1962 he was the director of the Institute of Biophysics, USSR Ministry of Health; from 1963 to 1965 he was the organizer and first director of the Institute of Biomedical Problems, USSR Ministry of Health.

Concurrently with his work at the MMA, A. V. Lebedinskiy headed in different years the physiological sector of the Psychophysiological Laboratory at the Leningrad Institute of Civil Aviation Engineers, Physiological Laboratory of the Leningrad Ophthalmological Institute imeni Girshman, physiological sector of the Brain Institute imeni V. M. Bekhterev and theoretical sector of the Leningrad Scientific Research Institute of Neurosurgery imeni A. L. Polenov.

A. V. Lebedinskiy was among the immediate disciples of Academician L. A. Orbeli and a vivid representative of his school. His multifaceted scientific interests enabled A. V. Lebedinskiy to make a valuable contribution to different areas of physiology, biophysics, radiobiology, space biology and medicine.

A typical distinction of scientific endeavors of A. V. Lebedinskiy was his desire to demonstrate physical patterns in biological processes, to use biophysical methods of investigation. This approach was inherent not only in work in the field of normal physiology, but various applied disciplines.

Investigation of physiology of sense organs was one of the important directions of research done by A. V. Lebedinskiy. His work in physiology of vision deals with investigation of photoreception, interaction of afferent systems, adaptation, visual acuity and field, depth vision, stability of clear vision, accommodation, electric sensitivity of nerve elements of the eye, visual tract and cortical centers, permeability of optic media and innervation of the pupil. A significant result of this cycle of studies was establishment of reciprocal relations between the rod and cone systems of the retina, and implications of this phenomenon to the process of dark accommodation, demonstration of the relaxing effect of sympathetic innervation on accommodation muscle, as well as the vasodilating effect of trigeminal nerve fibers on vessels of the ciliary body.

A cycle of experimental work done by A. V. Lebedinskiy and his co-workers dealt with trophic function of the nervous system. They demonstrated the significance of afferent innervation in origin of neurogenic dystrophy, role of spinal ganglia and their analogues in cranial nerves with regard to assuring the normal course of physiological regeneration processes. A. V. Lebedinskiy developed quantitative methods of evaluating the elastic and viscous properties of muscles and viscosity of the vascular wall for the purpose of biophysical analysis of trophic effect of sympathetic innervation.

Andrey Vladimirovich devoted a large part of his life to the study of biological effects of ionizing radiation. He created the physiological direction of modern radiobiology, advanced a number of basically new views on the origin of radiation lesions and explored the general physiological principles of effects of ionizing radiation. A. V. Lebedinskiy devoted much attention to the study of early reactions of the cardiovascular system, and he made a particularly comprehensive study of regulatory mechanisms in the irradiated organism. The main conclusions drawn from this work were the theses of change in functional state of all levels of autonomic regulation (from the cerebral cortex and hypothalamus to the postganglionic neuron) and involvement of neuroendocrine mechanisms in the reaction. These disturbances make more difficult the homeostatic function of the autonomic nervous system and could lead to restriction of adaptive processes in the irradiated organism.

Another direction followed by A. V. Lebedinskiy was investigation of permeability of different histohematic barriers. The discovered increase in exit of potassium ions through the cell membrane, along with findings of decreased electromotive force and flow [current?] of injury of irradiated muscle, served as the material argumentation for the theoretical thesis of Andrey Vladimirovich about development of persistent depolarization of synapses as the basis of the deleterious effect of ionizing radiation on excitable systems. Use of various biological photoreceptor models made it possible to demonstrate that ionizing radiation could be a stimulus for receptor structures.

In the last years of his life, A. V. Lebedinskiy worked with great enthusiasm in the area of space biology and aerospace medicine. Along with solving important practical problems in the area of biomedical support of spaceflights, work was done under the supervision of A. V. Lebedinskiy to investigate the effects on the body of various extreme factors associated with spaceflights, questions of habitability, problems of radiation safety of spaceflights. Many of the ideas of A. V. Lebedinskiy in the area of space medicine are important to this day.

A. V. Lebedinskiy was a prominent public figure. In 1955-1958, he represented the USSR in the UN Scientific Committee for Atomic Energy, where he actively implemented the humane policy of our government, which is fighting to stop nuclear tests and ban nuclear weaponry.

A. V. Lebedinskiy was very active in scientific and social work, having been a member of the board of the Moscow Society of Physiologists, chairman of the scientific council for the problem of "Radiobiology" under the USSR Academy of Sciences. He worked actively in the Society for Dissemination of Political and Scientific Information. A. V. Lebedinskiy was deputy editor of the journals, RADIOBIOLOGIYA [Radiobiology] and BULLETEN' EKSPERIMENTAL'NOY BIOLOGII I MEDITSINY [Bulletin of Experimental Biology and Medicine], a member of the editorial boards of the journal ATOMNAYA ENERGIYA [Atomic Energy] and "Radiobiology" section of the Great Medical Encyclopedia, a member of the editorial board of FIZIOLOGICHESKIY ZHURNAL SSSR [Physiological Journal of the USSR] and a member of the editorial board of EXCERPTA MEDICA.

The Soviet government appreciated highly the sociopolitical and scientific activities of A. V. Lebedinskiy, having bestowed upon him two Orders of Lenin, the Order of the Red Banner, Order of the Red Star, two Orders of the Red Banner of Labor and medals.

OBITUARY OF P. A. CAMPBELL

[Article by editorial board]

[Text] One of the pioneers of U. S. aviation and space medicine, P. A. Campbell, doctor of medicine, active member of the International Academy of Astronautics, expired in his 80th year.

P. A. Campbell had a long and interesting creative life. Having received his medical education and specialization in otorhinolaryngology in Chicago and Vienna, he devoted his life to aviation and space medicine. Dr Campbell was chief of the Department of Space Medicine and Chief of the U. S. Air Corps School of Aviation and Space Medicine.

Dr P. A. Campbell began in 1950 to investigate problems of cosmonautics, which had just emerged, and he studied the contribution of aviation medicine to its formation. In 1951, he participated in establishing the section of space medicine in the Association of Aviation and Space Medicine (United States) and headed this section.

The first symposium on "Medical and Biological Aspects of Cosmic Energy" was convened at the initiative of P. A. Campbell, and its proceedings, which he edited, were published in 1961. In 1965, his very interesting book, "Earthling--Astronaut--Citizen of the Universe?," was publsihed, in which he showed that man's penetration into space is the logical outcome of the entire history of civilization and, at the same time, the most important key element of history, which will radically influence future progress of science, technology, culture and moral-ethical aspects of life in human society.

P. A. Campbell organized and, for many years, headed the Committee for Space Rescue and Safety of the International Academy of Astronautics.

In 1973, Dr Campbell and his wife visited the Soviet Union and participated in the regular astronomical congress, which convened in Baku.

P. A. Campbell was notable for great erudition, he was a talented educator, lecturer and popularizer of science. He was highly tactful and a kind colleague.